AEROBIC TREATMENT OF LIVESTOCK WASTES

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THE NEED FOR A RIGOROUS STUDY of the aerobic biological method of livestock waste disposal prompted the assembling of the information in this bulletin. It should be of interest to anyone who wants to use the aerobic method of livestock waste handling and treatment, and especially to persons who design and develop such systems. Refer to Uniform Terminology for Rural Waste Management (1969) for definitions of terms.

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Contents

LIVESTOCK WASTE PROPERTIES 4
THEORY OF AEROBIC TREATMENT 5
LABORATORY STUDIES OF AEROBIC TREATMENT OF WASTES 7
DEVELOPMENT AND MUNICIPAL USE OF OXIDATION DITCH 14
THE IN-THE-BUILDING OXIDATION DITCH FOR LIVESTOCK WASTES . . . 19
AEROBIC LAGOONS 41
AERATED LAGOON SYSTEM WITH IRRIGATION — AN EXPERIMENTAL STUDY 47
SUMMARY AND CONCLUSIONS 50
REFERENCES 53

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AEROBIC TREATMENT OF LIVESTOCK WASTES

Large volumes of manure have been produced on small land areas since the advent of intensified confinement livestock systems. The amount of wastes produced by livestock in the United States has been estimated to be nearly two billion tons (Wadleigh, 1968). This is nearly ten times the excrement produced by the human population of the United States (Taiganides, 1967). However, there is much more dilution water added to domestic wastes than to livestock wastes.

Until the last few years manure could simply be spread on the farmer's field every few months. The farmer appreciated the fertilizer value, and no one minded the odor. However, with the development of cheap, efficient commercial fertilizer and the proximity of neighbors who object to the manure odor, this is no longer the case.

It has been found (Van Arsdall, 1962) that "spreading solid manure on cropland, rather than dumping it in a disposal area, is a profitable practice because there is little difference between spreading and disposal costs." But with liquid manure systems which are very popular in hog confinement production, the report states: "The most profitable practice for the farmer who raises hogs in confinement is to dispose of the liquid manure in a lagoon and use commercial fertilizer on his fields." No doubt the same would be true for producers who raise other types of livestock in confinement.

The pollution of both surface and ground water supplies by animal wastes is receiving the attention of various health and pollution control agencies. In addition, land is not readily available during much of the year for the immediate spreading of animal wastes. For these reasons, farmers have begun looking for a low-cost, manure storage method which will not give rise to intolerable odors and insect breeding (Dale, 1968). They also want a method of storing manure for a longer period of time and closer to the production unit.

As a result, researchers have concentrated a great deal of effort toward developing a workable, odorless method of liquid waste disposal. One of the simplest methods of odorless waste treatment is the aerobic biological treatment process. The two major forms of aerobic treatment for municipal wastes are the activated sludge process and the trickling filter. Extended aeration, a modification of the activated sludge process, has primarily been used to treat livestock wastes aerobically. Two extended aeration processes, the oxidation ditch and the aerated lagoon, will be discussed in this report.

LIVESTOCK WASTE PROPERTIES

The design and operation of any biological treatment unit depends on the nature of the wastes to be treated. Wastes vary in concentrations of biodegradable components, and appropriate bacterial cultures must be developed to treat different organic compounds in the waste.

Housing and management conditions are unique for each type of livestock and they influence the amount and nature of the wastes produced. Differences in wastes are caused by differences in the size, diet, and metabolism of the animals (Blosser, 1964). Swine and poultry consume highly digestible rations and therefore produce a relatively small amount of waste compared with cattle on high-roughage rations. Also, simple-stomached animals such as swine produce excreta that is somewhat similar to that of humans (Loehr, 1968).

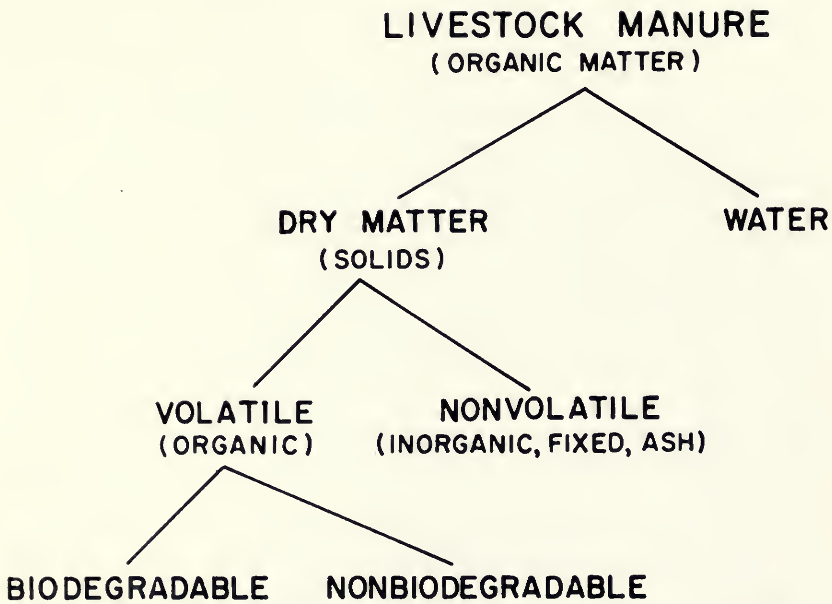
The manures from ruminants and herbivores, such as cattle and hogs, are different. Ruminants tend to produce relatively large amounts of wastes when compared with the amount of feed consumed. These wastes have compositions different from wastes of simple-stomached animals. Urinary wastes from herbivores tend to be more alkaline because diets are high in compounds such as potassium, calcium, and magnesium. The bacteria in the stomachs of ruminants utilize cellulose feeds. There are, however, certain compounds such as lignin which accompany cellulose in plants and which are difficult to digest in the rumen (Blosser, 1964).

Animals in confinement are fed a ration formulated to cause the greatest weight gain in the shortest time. Highly efficient feed consumption by the animal is required for continuous and rapid weight gain. Wastes produced under these circumstances will contain more pollution material than wastes produced by animals in which weight gain is less important. When the nutritive content of a ration exceeds the optimum

Table 1. — Suggested Values for Manure Defecation Rates, per 1,000 Pounds Live Weight in Confinement Animal Production (Farm Animal Wastes — 1969)

	Dairy cattle	Beef cattle	Hens	Pigs	Sheep
Raw manure (RM), lb. per day	88	60	59	50	37
Total solids (TS), lb. per day	9	6	17.4	7.2	8.4
Total solids, percent RM	10	10	30	14.4	22.7
Volatile solids (VS), lb. per day	7.2	4.8	12.9	5.9	6.9
Volatile solids, percent TS	80	80	74	82	82
BOD_5, lb. per day	1.7	1.5[a]	4.4	2.1	.7
BOD_5, lb. per lb. VS	.233	.252	.338	.363	.101
BOD_5 per COD, percent	16	..	28	33	..
Nitrogen, percent TS	4	9.8	11.5	5.6	..
Phosphoric acid, percent TS	1.1	..	..	2.5	..
Potassium, percent TS	1.7	..	..	1.4	..

[a] Values for beef were estimated by the authors.



Components of livestock wastes important to biological treatment. (Fig. 1)

level, an animal will excrete more of the nutrient material. For example, if the level of protein feeding is raised beyond a certain point, the protein is less effectively digested and more passes into the feces (Loehr, 1968).

The composition of animal manure is dependent upon the animal's environment and its level of productivity. Additives such as antibiotics, copper, arsenic, grit, or sand in the feed also affect the biochemical properties and the physical characteristics of the manure (Loehr, 1968).

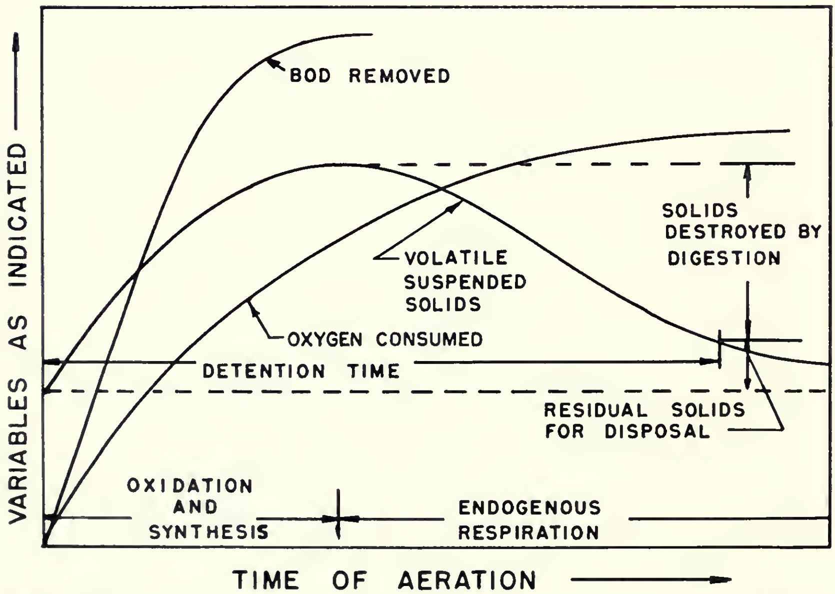
Livestock wastes added to oxidation ditches and aerobic lagoons are often undiluted and do not contain bedding. There are only limited data available on the properties of livestock wastes, so where possible the livestock producer should have a sample of his specific waste analyzed before constructing a waste treatment facility. The properties in Table 1 may be used when this is not possible (Farm Animal Wastes-1969). Also, Figure 1 shows livestock waste components, and it may be helpful in the following discussions of treating wastes biologically.

THEORY OF AEROBIC TREATMENT

Heterotrophic microorganisms need organic substrates as food to grow either aerobically or anaerobically, and livestock manure is a good food source for many groups of bacteria. Aerobic bacteria (aerobes) require dissolved oxygen for metabolism, using oxygen as a hydrogen acceptor.

Anaerobic bacteria use other hydrogen acceptors, such as sulfate and carbon dioxide. Another group of microorganisms are facultative and they gain energy by either the aerobic or anaerobic pathway. By either route, the bacteria must have available carbon, nitrogen, and a supply of various trace nutrients in the substrate. They must also be in an environment with a satisfactory pH and temperature.

Aerobic treatment for the removal of biodegradable organic matter from liquid wastes is an odorless process and consists of two phases operating simultaneously. One phase is biological oxidation that has by-products such as carbon dioxide and water and it yields energy. The second phase utilizes the energy from the oxidation phase for synthesis of new cells, as shown by the following simplified equation: microbial cells + organic matter + $O_2 \rightarrow CO_2 + H_2O + NH_3$ + more cells. Oxygen must be supplied continuously and the amount required depends on the quantity of biochemical oxygen demand (BOD). Only that fraction of the wastes which has been oxidized can be considered stabilized. The synthesized microbial cells are not in the most stable form, but can be settled and separated from the system if desired. Even with long detention times, there will be in the system solids residue build-up (sludge) that must ultimately be disposed of. The sludge accumulation rate in a municipal activated sludge system is about 11 percent of the BOD removed per day (Stewart, 1964).



The aerobic metabolism process. **(Fig. 2)**

In a suitable environment (unlimited food supply, sufficient oxygen, and so on) aerobic bacteria have a cycle that begins with a period of acclimatization; then they reproduce at an exponential rate (logarithmic growth period) as shown in Figure 2. During this period, the consumption of oxygen increases sharply, food substrates (organic wastes) are oxidized, and the mass of cells increases. An important parameter is the food-to-organism ratio (F:M) and this is approximated by the pounds of BOD_5 applied per day per pound of volatile suspended solids (VSS) in the treatment plant (lb. BOD_5/day/lb. VSS) (Symons and McKinney, 1958).

The rate of reproduction and oxygen consumption drops if the suitable environment is altered by such factors as depletion of the food or oxygen supply or a buildup of toxic products, or when space for growth diminishes. The final stage of the cycle is endogenous metabolism wherein low levels of oxygen and nutrients are needed. As available nutrients diminish below the level needed for survival, then energy or other factors in the environment become unsatisfactory for maintenance of life, and the cells disintegrate, releasing nutrients for the survivors.

The complete bacterial cycle occurs when the system is batch fed. However, if nutrients are supplied continuously, the cycle is in a continuous process with all phases occurring simultaneously. The predominance of any particular phase will depend upon the operation of the particular system.

A maintenance of one to two milligrams per liter of dissolved oxygen (D.O.) in the liquid wastes is sufficient to maintain aerobic conditions. The air rate supplied for aerobic digestion is usually not a critical parameter where air is used both as the source of agitation and for microorganism growth, since experiments with municipal wastes have shown that the air requirements for oxidation are usually small compared with the amount of agitation needed to keep solids in suspension.

LABORATORY STUDIES ON AEROBIC TREATMENT OF LIVESTOCK WASTES

Some form of aerobic treatment of livestock wastes appears certain to be used in the future in animal production enterprises. Odor control alone may be sufficient to make it a feasible operation. However, there are other advantages that may add to its demand. Some of these are: (1) partial decomposition of volatile (organic) solids into water and odorless gases such as carbon dioxide, (2) destruction of most pathogenic organisms, (3) reduction in the pollutional characteristics of the wastes, i.e., the lowering of the oxygen demand, and (4) concentration of the minerals which may be more readily applied to land by some system.

In an effort to determine the effects of various aerobic treatment methods and procedures, several laboratory experiments have been conducted at the University of Illinois at Urbana-Champaign and at Purdue University. These are briefly summarized under the following types of livestock wastes.

Swine Wastes

Aerobic digestion of swine manure has been studied since 1964 at the University of Illinois. The first laboratory study used batch loading and resulted in a recommendation for an aerobic digester of 6 cubic feet of liquid per 150-pound hog (Irgens and Day, 1966). This volume recommendation is inversely proportional to a loading rate given as pounds of daily BOD_5 per unit volume of digester. It was also found that 2,500 cubic feet of air was required per pound of BOD_5 at 3 percent efficiency of oxygen utilization.

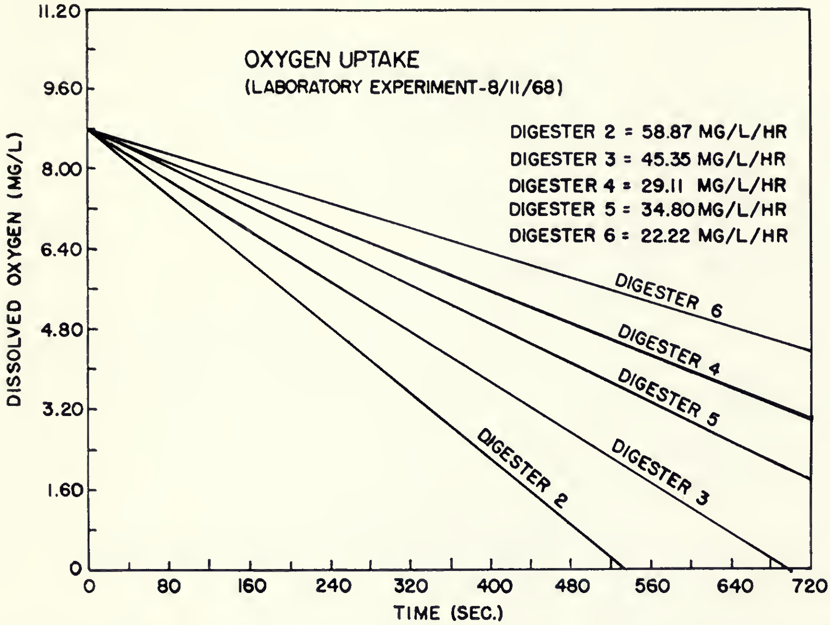
In the laboratory treatment system, better results were obtained with daily loading than when loads were added at weekly intervals. Thus, the authors concluded that odorless aerobic treatment could be obtained under the self-cleaning slotted floors of a confinement building by connecting the ends of the liquid-manure gutters and adding a rotor aerator. This oxidation ditch would keep the solids suspended, circulate the liquid manure, and add oxygen. The first field tests in the fall of 1966, using volumes of 6 cubic feet per hog, however, gave poor performance and produced excessive amounts of foam — indicating that more laboratory work was needed.

Further laboratory studies, using volumes comparable to 6, 8, 10, 12, 16, and 20 cubic feet per finishing hog (based on BOD_5 of the waste from a 150-pound hog) were designed by Jones et al. (1969B). The earlier laboratory study used swine manure strained through one-eighth-inch-mesh wire screen to remove grain particles, and this was diluted before being added to the digester. The waste in the second study was merely collected and added to the digesters daily, with no prior straining or dilution. The volume was kept constant by drawing off a volume equal to the volume added each day.

At the beginning of the study, waste from the liquid-manure pit under a hog-finishing building was collected and frozen. The BOD_5 (seeded) of the waste was 17,500 milligrams per liter, the ultimate BOD was 54,000 milligrams per liter, and the BOD rate-constant (to the base e) was 0.08.

From this second laboratory study, the following observations were made:

1. The digester with a volume of 6 cubic feet per hog consistently foamed for two to three hours after its daily feeding. By the third week,



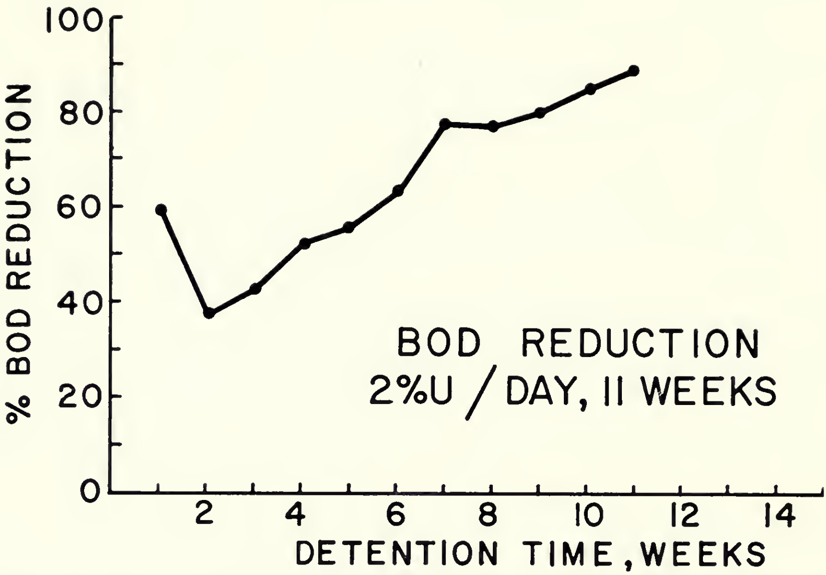
Oxygen uptake rates for the mixed liquor in the laboratory digesters after 13 weeks of operation. (Fig. 3)

it was obvious that this digester was heavily overloaded. Its operation was discontinued.

2. After 13 weeks, the digesters had mixed-liquor BOD_5's of 2,500, 2,400, 1,700, 2,100, and 1,700 milligrams per liter and supernatant BOD_5's of 45, 65, 40, 70, and 50 milligrams per liter, respectively, for volumes of 8, 10, 12, 16, and 20 cubic feet per hog. Mixed-liquor BOD_5 reductions varied from 82 to 86 percent, with the volume of 12 cubic feet per hog being the most efficient. The mixed-liquor total solids level after 13 weeks ranged from 2.1 percent at a volume of 8 cubic feet per hog to 1.7 percent at a loading rate of 20 cubic feet.

3. After 13 weeks of operation, the digesters had oxygen uptake rates of 59, 45, 20, 35, and 22 milligrams per liter per hour respectively for volumes of 8, 10, 12, 16, and 20 cubic feet per hog (Fig. 3).

In contrast with the first laboratory study at the University of Illinois (where the waste was strained before treatment), these results indicated that volumes of 6 cubic feet or less per hog were not suitable for in-the-building, oxidation-ditch treatment because of the serious foaming problem. However, volumes of at least 8 cubic feet per finishing hog resulted in good treatment and no serious foaming.



Reduction of mixed-liquor BOD_5 for the chamber with a daily loading of 2 percent by volume. (Fig. 4)

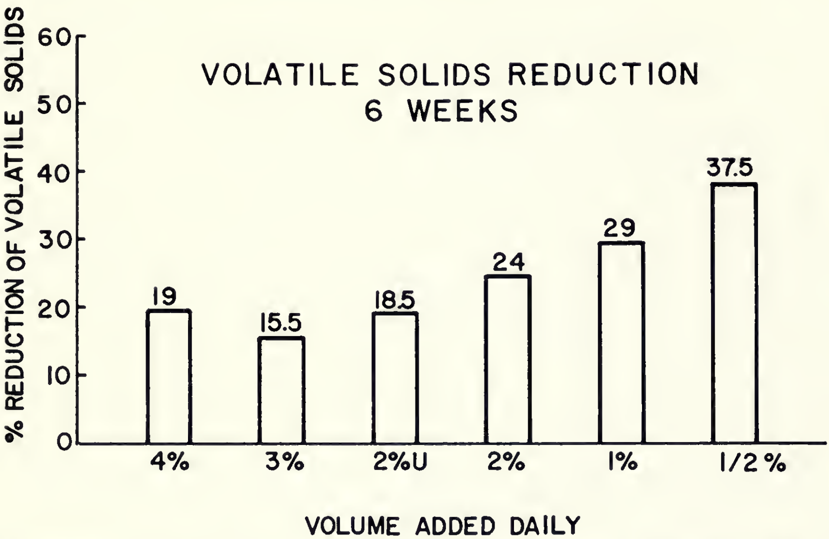
Dairy Cattle Wastes

Some aerobic decomposition properties of dairy cattle manure were studied by Dale and Day (1967). The daily manure production from seven high-production Holstein dairy cows at the University of Illinois averaged 107.8 pounds per day for a 1,500-pound cow. The BOD_5 per day per cow was 2.76 pounds and the manure slurry contained 12.5 percent solids.

Six loading rates were studied: ½-percent, 1-percent, 2-percent, 3-percent, and 4-percent, strained manure slurry added as related to the volume in the container; and 2-percent unstrained manure slurry. These rates were added to the digesters for 11 weeks. The mixtures were aerated for an additional 13 weeks without manure being added. The work was conducted at room temperature.

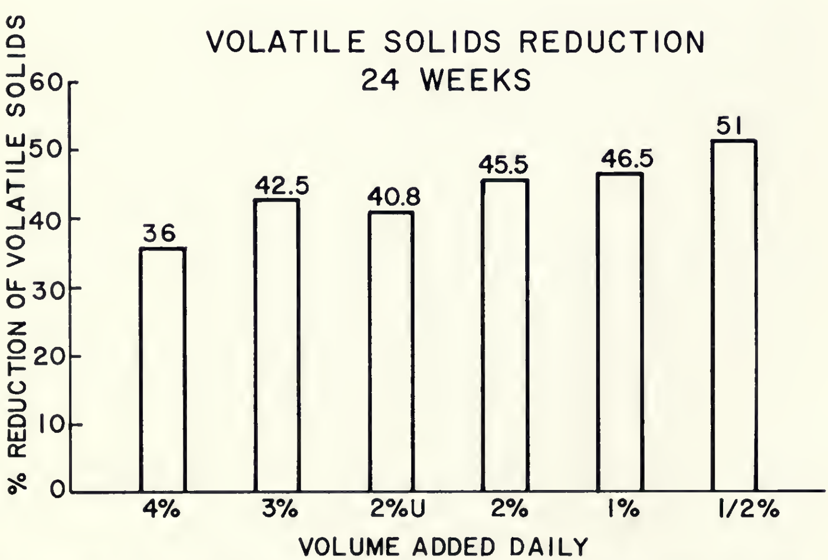
The percent reduction of BOD_5 for the 2-percent digester, computed on the basis of the BOD_5 added versus the BOD_5 remaining is plotted in Figure 4. In the beginning there was a low rate of BOD_5 reduction. Since the digesters were not seeded initially and the microorganisms generally present in raw dairy cattle manure are facultative, an acclimation period of three to five weeks may be required to develop a good aerobic culture.

Decomposition of the volatile solids varied from a low of 22 percent at the end of six weeks for the chamber to which 3 percent was added daily to a maximum of 51 percent for the chamber to which ½ percent was

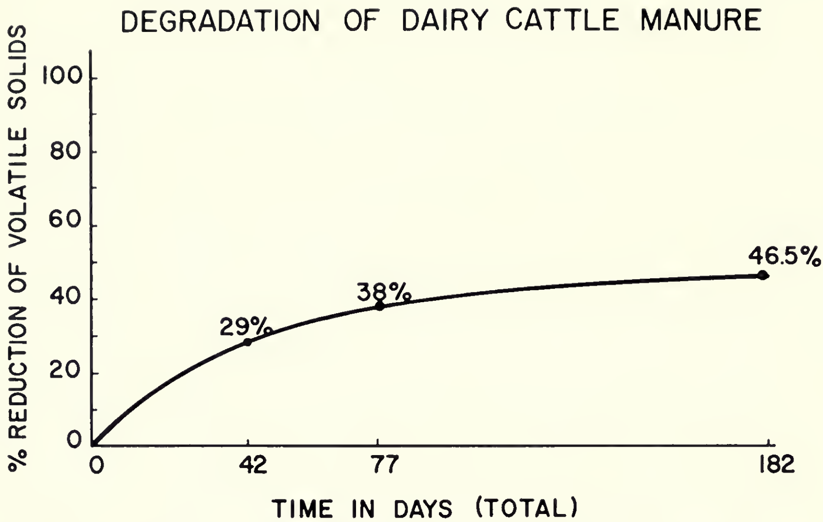


Reduction of volatile solids in the chambers after six weeks of aeration. (Fig. 5)

added daily. The decomposition percentages of the volatile solids at the end of six weeks and 24 weeks respectively are shown in Figures 5 and 6. A plot of the trend throughout the 24-week period of the chamber to



Reduction of volatile solids in the chambers after 24 weeks of aeration. (Fig. 6)



Reduction of volatile solids in the chamber with a daily loading of 2 percent by volume throughout the experiment. (Fig. 7)

which 1 percent was added daily is shown in Figure 7; the 1 percent per day rate is equivalent to the addition of 2.52 grams of dry matter per day. Using the dry-solid basis, analysis of the solids after 24 weeks of aeration for the 1-percent chamber was 25.6 percent ash, 2.65 percent nitrogen, 0.92 percent potassium, and 1.18 percent phosphorus. For the 4-percent chamber the analysis was 18.3 percent ash, 2.06 percent nitrogen, 0.73 percent potassium, and 1.00 percent phosphorus.

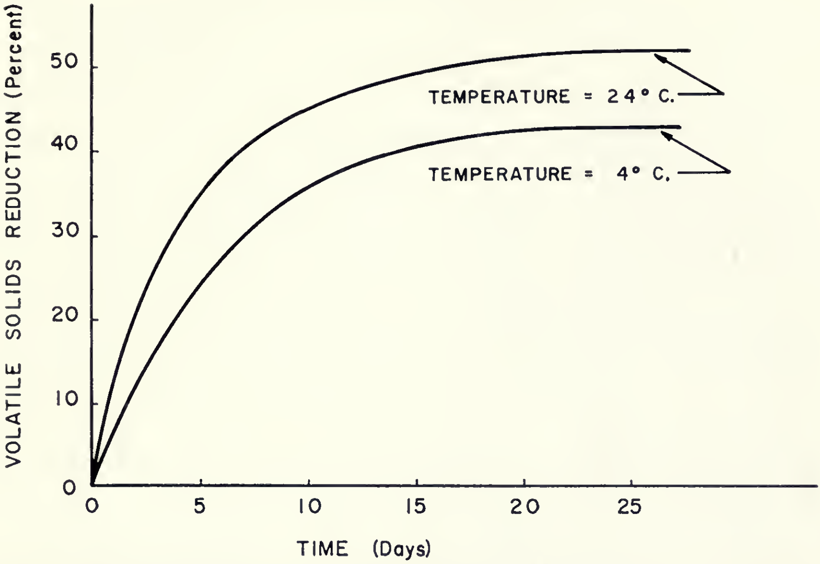
An experiment to study the effect of temperature on the aerobic decomposition of dairy cattle waste was conducted at Purdue University (Bloodgood and Robson, 1969, and Robson, 1969). Aeration units at temperatures of 4° C. and 24° C. were operated at loading rates of 60, 80, 100, and 120 grams of manure per day with an 85-percent moisture content. Ground Holstein dairy cattle manure in slurry form was added daily to each digester for 28 days.

Average reductions obtained were: for volatile solids, 42.3 percent (at 24° C.) and 20.1 percent (at 4° C.); for COD, 53.6 percent and 24.5 percent; and for Kjeldahl nitrogen, 43.5 percent and 15.9 percent.

The following conclusions were drawn from these studies with aerobic treatment of dairy cattle wastes.

1. The BOD_5 may be reduced up to 98 percent if the wastes are digested for a sufficient length of time.

2. Volatile solids can be reduced by 40 to 50 percent if the wastes are digested for a sufficient length of time.



Comparison of the effect of two temperatures (4° C. and 24° C.) on volatile solids reduction. (Fig. 8)

3. Temperature has an effect on decomposition rates and the final decomposition obtained. At 4° C. about 20 percent of the volatile solids of blended dairy cattle manure may be decomposed, as contrasted to a decomposition of 43 percent at 24° C. (Fig. 8).

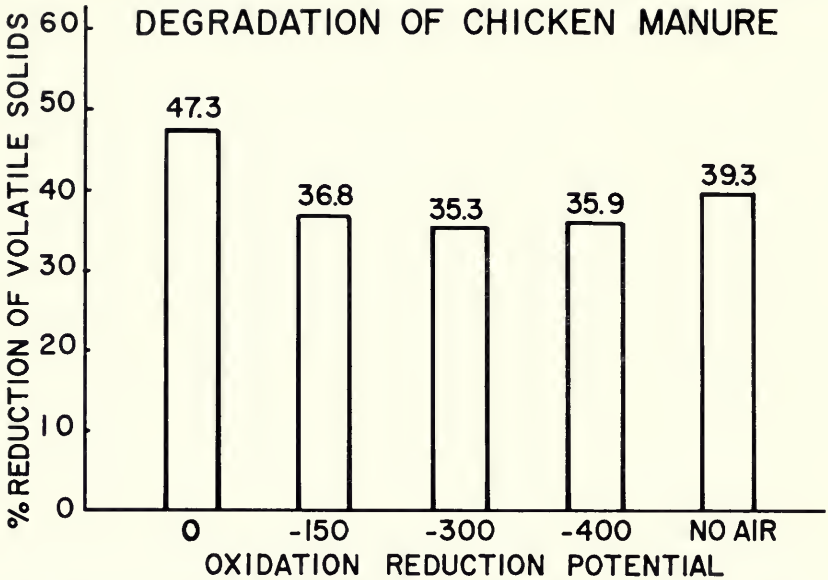
4. The breakdown of the volatile solids appears to be only slightly affected by the higher loading rates.

5. Raw, unstrained cow manure does not decompose as rapidly as manure from which coarse materials (stems, grains of corn, and so on) have been removed.

Poultry Wastes

Ludington et al. (1969) conducted research to study hydrogen sulfide production and degradation in the threshold between aerobic and anaerobic treatment of chicken manure. The ORP (oxidation-reduction potential) measurement responded to the presence or absence of aeration and permitted continuous monitoring of conditions from aerobic to strictly anaerobic. The ORP was incorporated into an automatic control system to regulate aeration.

Tests were conducted with no aeration and with ORP controlled by aeration at 0, -150, -300, and -400-millivolt (using a calomel electrode). The tests were done in a room at 55° F. with daily feeding and no attempt was made to control the pH of the chamber contents. Degradation (reduction in volatile solids) of the waste is shown in Figure 9.

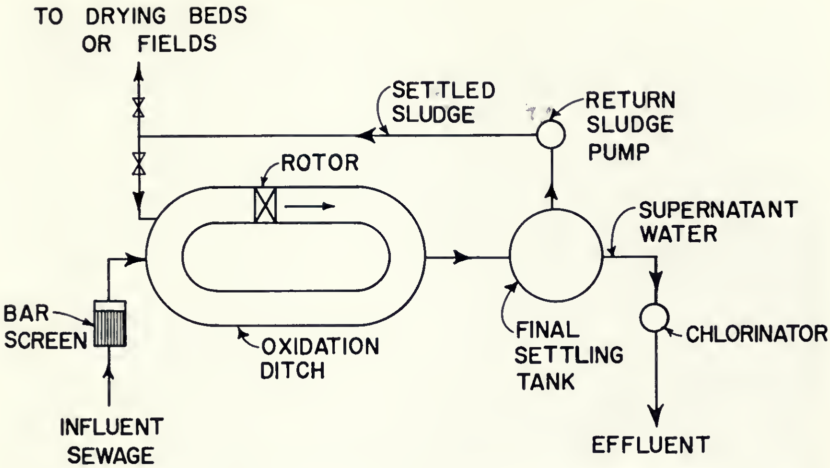


Reduction in volatile solids of poultry manure as related to oxidation reduction potential. (Fig. 9)

Other tests were conducted to determine the time required for chicken manure stored under controlled conditions of -350, -400, and -450 millivolts and no air to produce hydrogen sulfide after termination of aeration. An average of only 12.8 cubic feet of air per day per chicken was required to maintain an ORP of -400 millivolts and prevent the release of hydrogen sulfide. Manure stored at -400 millivolts had a 35.9-percent reduction in volatile solids. Chicken manure stored with aeration at zero ORP also produced no hydrogen sulfide, but had a higher reduction of volatile solids.

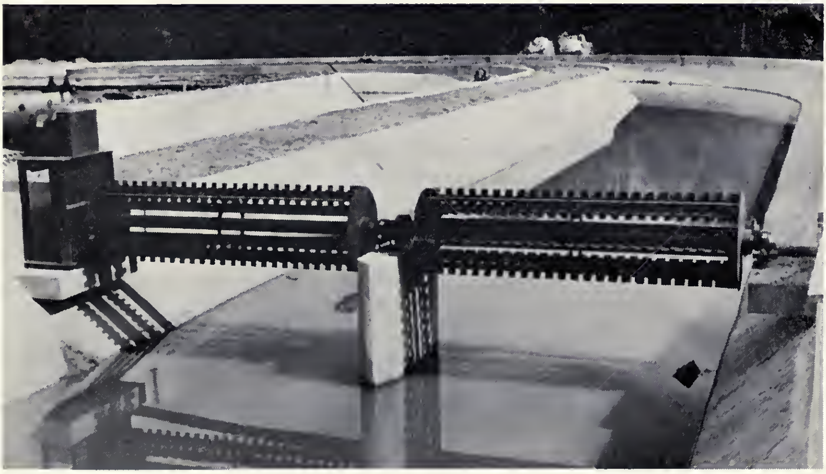
DEVELOPMENT AND MUNICIPAL USE OF THE OXIDATION DITCH

The oxidation ditch was developed during the 1950's at the Research Institute for Public Health Engineering (TNO) in the Netherlands as a low-cost method of purifying non-pretreated sewage emanating from small communities and industries (Pasveer, 1963). The oxidation ditch is a modified form of the activated-sludge process and may be classed as an extended aeration type of treatment. Aerobic bacteria use the organic matter in the waste as food for their metabolic processes, thus reducing the biologically degradable organics to stable material, with carbon dioxide and water as byproducts.

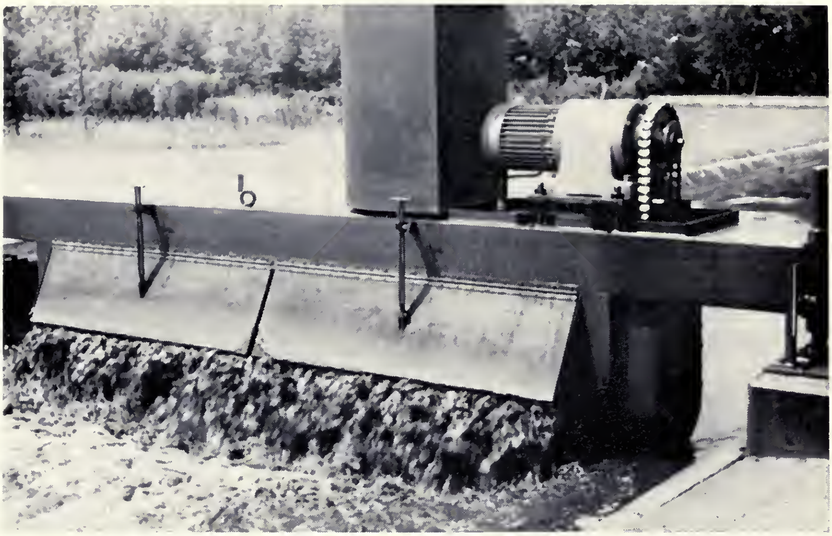


A flow diagram of an oxidation ditch treatment plant for municipal wastes. (Fig. 10)

The oxidation ditch is made up of two principal parts — a continuous open-channel ditch, usually shaped like a race track, and an aeration rotor that supplies the oxygen and circulates the ditch contents. A minimum liquid velocity of about one foot per second must be maintained so that the solids will be kept in suspension and will not settle out. Figure 10 is a schematic drawing of a typical municipal treatment plant. Figure 11



Cage rotors for a municipal oxidation ditch. Rotor covers are removed. (Photo courtesy of Lakeside Engineering Corp.) (Fig. 11)



A cage rotor in operation in an oxidation ditch in the Netherlands. Motor cover raised. (Fig. 12)

shows typical cage rotors and Figure 12 shows one in operation. Berk (undated) has summarized the principles of operation of the oxidation ditch for sewage treatment.

The oxidation ditch is presently being used by several communities in Europe and is being used to a limited extent in this country. The oxidation ditch is only a part of the overall treatment process in a municipal plant. There is normally no primary settling tank used; however, the ditch is usually preceded by a bar screen to remove from the sewage large floating debris which might damage the rotor. For the system to operate at high efficiency of waste treatment, the sludge must have good flocculating characteristics so that solids and supernatant can be separated when quiescent conditions are provided (Fig. 13). Thus, the ditch is usually followed by a settling tank which allows the clarified effluent to be drawn off and discharged into a water course after chlorination. In many municipal treatment plants, the settling is accomplished by merely shutting off the rotor for an hour or so and then drawing supernatant off the top. Regardless of where the settling is done, the concentrated sludge must still be disposed of. A large part of these solids actually consists of bacterial cells (25 to 50 percent) and portions of the solids are always retained in the ditch to help treat the incoming raw sewage. The oxidation ditch is operated as a closed system and the net growth of volatile suspended solids will increase so that it will be necessary to periodically remove

Separation of solids and supernatant after approximately 30 minutes of quiescent conditions. (Fig. 13)

some sludge from the process. Removal of some sludge lowers the concentration in the ditch and keeps the metabolism more active. Excess sludge may be dried directly on sludge drying beds or stored in a holding tank or in a sludge lagoon for later disposal.

Because of the large volume of the aeration ditch and the fact that suspended solids in the oxidation ditch are kept fairly high (4,000 to 8,000 mg./l.), the total amount of floc in the plant is from 10 to 30 times as great as that in a municipal activated sludge plant. The rate of BOD_5 loading is correspondingly lower. Municipal oxidation ditches have a low F:M ratio (about 0.05:1) compared with the ratio in municipal activated sludge plants (about 0.5:1). It is evident that if a sufficient amount of oxygen is provided at this very low loading rate, the floc will be in an advanced stage of mineralization. As soon as there is a sufficiently high sludge content in

the ditch, the operation should allow for regular removal of a quantity of surplus sludge to maintain a constant suspended solids content. In this manner, a suitable concentration of floc can be maintained and excessive salt concentrations can be prevented. Pasveer (1960) makes the following conclusions about the operation of an oxidation ditch:

1. The energy required for oxygenation will be greater than is the case in a conventional activated sludge plant since the total quantity of sludge in the ditch must be brought to an advanced state of mineralization. However, the cost of the additional energy is still small compared with the saving in capital costs.

2. The very large amount of floc in the system renders the process insensitive to peak BOD_5 loads.

3. It is to be anticipated that the purifying capacity of an oxidation ditch will be even less susceptible to the influence of low temperature than the conventional activated sludge process. Pasveer also states that in the municipal oxidation ditch, the fresh sludge carried by the sewage and the sludge formed in the purification process are mineralized to such an extent that the surplus sludge can be dried without causing objectionable odors. This means that a sludge fermentation tank is not needed. Furthermore, by selecting a suitable working method it is possible to avoid building a secondary sedimentation tank with a sludge return system. With a loading rate of 89 cubic feet per pound BOD_5, settled supernatant can be removed from the ditch periodically in such a manner that all of the floc (sludge) is retained in the system. According to Pasveer's observations in municipal ditches, about 1 pound of dry sludge solids was produced for every 2.5 pounds of BOD_5 added to the ditch. The sludge had an ash content of 24 percent to 27 percent in the winter and 30 percent to 32 percent in the summer.

The sludge taken from a municipal oxidation ditch dries to 10 to 12 percent solids after about one day when spread four inches thick on a sand bed (Pasveer, 1960). After six weeks, the sludge can be handled with a pitch fork. If the soil is permeable under the sand beds, the drying beds will not need to be drained. There are several alternatives insofar as sludge disposal is concerned. The best method is probably to place the sludge on the land to reclaim the fertilizer value from the waste. The sludge may or may not be dried first. The physical structure of dried sludge taken from a municipal oxidation ditch is greatly improved if the sludge is left lying on sludge-drying beds throughout the winter. The nitrogen content is high, about 6 percent of the dry solids, and the organic matter is 65 to 75 percent of the dry solids.

Anaerobic digestion of the sludge from extended aeration has been tried in municipal plants, both in digestion tanks and in lagoons (Pasveer, 1960).

The sludge does not decompose well, however, because of the high degree of mineralization, as witnessed by the fact that only about half as much gas is produced in the digestion of the sludge as compared with sludge from a conventional activated sludge plant.

THE IN-THE-BUILDING OXIDATION DITCH FOR LIVESTOCK WASTES

The success of the oxidation ditch in meeting the low-cost treatment requirements of small communities has interested livestock producers. The oxidation ditch may be a means of lessening anti-pollution pressures from encroaching urban areas. In addition, the oxidation ditch appears to meet the major requirements of a livestock waste treatment process: decrease in labor requirements, reduction in volume of solids, reduction of odors, and reduction of the pollution potential of the manure.

Approximately 200 oxidation ditches are now in operation in livestock buildings across the United States. Some of the reasons why the oxidation ditch was selected over other possible treatment schemes are as follows:

1. It is an odorless process, with the exception of small amounts of ammonia at times and an earthy odor given off by the contents.

2. It has the ability to handle shock loads. Once the system is operating properly, the ditch can absorb brief heavy loadings without upsetting the biological process.

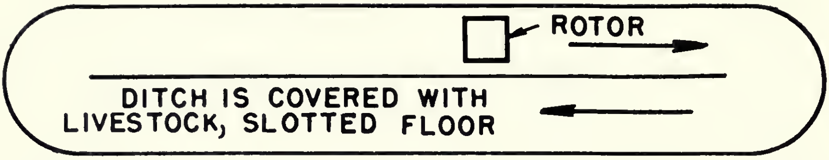
3. It fits well into the farmer's work schedule, requiring very little attention or maintenance.

4. The process fits readily under the labor-saving slotted floor system, eliminating extra pumping or hydraulic systems to move waste from where it is produced to the treatment plant.

5. The oxidation ditch is a reasonably inexpensive process, both in capital cost and in operating cost. The capital cost is low because the manure collection gutter is usually already present and the only expenditure required for the channel is to round the corners and connect the ends of the gutter. Therefore, the main capital cost is the rotor itself, around $300 per horsepower (including motor and drive) (Newtson, 1970). The major operating cost would be the power source required to operate the rotors (usually 2- to 5-horsepower motors).

Construction

The most common shape for a livestock oxidation ditch is in the form of a race track (Fig. 14); however, several variations have been tried. Probably any configuration could be used as long as a continuous loop is maintained. However, excess bends increase the frictional resistance



Common shape of a livestock oxidation ditch made by dividing a manure collection gutter. (Fig. 14)

and can retard the flow. A median width of 16 feet or greater is maintained in most municipal plants. For the sake of economy and because of existing conditions, a median strip this wide is seldom used in livestock operations and 180-degree turns are common. Observations indicate that the eddy currents caused by 180-degree turns may affect the flow after the liquid passes the turn. Where such sharp bends do exist, it may be necessary to install deflector vanes around the corners. However, solids often settle out in the channel opposite the rotor after the flow has left the deflectors. At any rate, the deflectors do prevent settling at the ends of the channels, but more research is needed to lower the flow resistance at corners. Also, better flow is obtained if the rotor is located in the middle one-third of the straightaway rather than near a sharp turn.

Most livestock ditches are completely lined with concrete; however, asphalt, plastic, and rubber liners may be used where the sides are sloped. When the ditch is located under a slotted-floor building, the sidewalls are generally vertical and lined with concrete.

There are two methods of discharging waste from the oxidation ditch — batch or continuous flow. If the system is the batch-discharge type, mixed liquor is allowed to accumulate in the ditch as raw waste is added. Then the mixed liquor is removed periodically by pumping. The depth of the liquid in the ditch is usually varied in this type of operation and requires that the rotor be raised at intervals to prevent it from being too deeply immersed. This requires some management and time on the part of the operator, and livestock producers usually bypass it in favor of the continuous-discharge method. With this method the liquid level is controlled by an overflow and remains constant. The rotor is operated continuously at a constant immersion depth. Most livestock producers prefer to simply let the mixed liquor in the ditch overflow and discharge by gravity into a lagoon or holding tank.

Start-Up

To start the aerobic process in the oxidation ditch, the empty manure channel should be filled to the desired operation level with tap water. The rotor can then be started at the desired blade immersion. Foaming is

often a problem during start-up. Initially, with a small microbial mass in the ditch, there will be certain surface-active materials in the manure which will not be readily metabolized and foam may result. This foam is a very light fluffy type and can be controlled with antifoam agents such as vegetable oil, petroleum oil, and various commercial products. It can also be controlled with a water spray. Once the microbial population increases to around 2,000 milligrams per liter of suspended solids, the start-up foaming should subside (Day and Converse, 1967).

If possible, animals should be added gradually to the production unit. After a few weeks of operation, the ditch can then be loaded to design capacity. Another option would be to pump activated sludge from an operating plant into the ditch to be started. Based on data obtained at the University of Illinois, a continuous-discharge ditch may take up to 12 weeks to become acclimated to the waste loading (Day et al., 1969). Therefore, it would seem that the ditch should probably never be completely flushed out, but rather a portion of the ditch contents should be replaced with tap water when the solids or mineral concentration becomes too high. At least 10,000 milligrams per liter of volatile suspended solids should be maintained in the ditch when the ditch is in full operation.

It should be emphasized here that an oxidation ditch should never be started when septic manure is in the ditch. This situation can give rise to extremely dangerous gases, foaming, and odors. In general, when manure has been allowed to stand in an oxidation ditch without aeration for more than three days, at least half of the contents of the ditch should be removed and replaced with tap water before starting the rotor, and even then extreme caution should be taken to provide adequate ventilation for animals and humans in the building. All ventilating fans should be operating and doors should be left open for about 24 hours after starting the rotor. If there is any doubt as to whether adequate ventilation can be obtained in the building when the rotor is started, the animals should be removed. Several animals have died in the last few years from gases during agitation of septic manure, and also from foam inundation.

Operational Problems

The oxidation ditch is probably the simplest and easiest to maintain of all waste treatment systems in use today. However, no waste treatment plant is maintenance free. Every system must have regular maintenance and good management if it is to function properly over an extended period of time. The most critical period of operation for any biological system is start-up. Start-up problems were discussed above and will only be mentioned here.

If adequate oxygen is not maintained in the ditch, anaerobic bacteria will develop and produce end products which are quite obnoxious and odorous. Some anaerobic end products are also surface active so that foaming usually accompanies the odor. Although it can be controlled temporarily with antifoam agents, the foam is best controlled by adding adequate oxygen to the ditch contents. If the mechanical system cannot supply the needed oxygen, relief may be obtained by adding a hydrogen acceptor such as ammonium nitrate or sodium nitrate (McKinney and Bella, 1967). Once the system is completely aerobic, the foaming will subside.

Some ammonia is often given off as urine drops into the ditch. In a properly operating ditch, nitrification will convert the ammonia to nitrates. If the rotor is adding insufficient oxygen to the waste, the ammonia may be liberated to the atmosphere. A slight odor of ammonia will always be present in a building because of urine splashing against the slats, but a strong ammonia odor may be a sign of insufficient oxygen in the ditch.

Settled solids can be a nuisance to ditch operation. Not only do they reduce the effective dilution of incoming wastes, but they may undergo anaerobic decomposition and create foaming problems. Care should be taken in the hydraulic design of the system to prevent solids accumulation in the bottom of the ditch (see the section on ditch velocity).

McKinney and Bella (1967) tell of one of the operational problems experienced at the Paul Smart farm, where the system was apparently aerobic but was foaming significantly. It was found that solids were settling out in the corners just before the rotor. These solids underwent anaerobic decomposition and released their surface-active end products to the upper water. Adequate oxygen prevented odors, but the material hit the rotor before it could be metabolized and foaming resulted. Removal of the settled solids eliminated the problem. McKinney and Bella also state that "at no time has foaming ever been noticed except at start-up and with anaerobic conditions. Foaming may be the best indicator of trouble somewhere in the system." Also, cleaning detergents and disinfectants must be used with discretion, as excessive amounts in the ditch can cause foaming and other problems. Not only is foaming an indication that the ditch is not treating the waste properly, but the foam may rise up through the slats and endanger penned animals. There have been reports of animal suffocation caused by oxidation ditch foam. J. Stevenson has developed a foam switch as a safeguard to be installed underneath a slotted floor. If foam rises to slat level, the switch stops the rotor. This switch is available from Thrive Centers, Inc., Fairbury, Illinois.

Oxidation ditches are simple in construction and operation. The major problem in their operation is with the rotor bearings. It is essential that the unit be easy to remove so bearings can be replaced. During normal operation, the bearings must be lubricated at least once a week. Another problem lies in the drive between the motor and the rotor (McKinney and Bella, 1967). The belt drives have a tendency to absorb the shock of blade contact with the water better than chain drives. It appears that the belts slip slightly with each impact with a net result of less wear on the equipment. The two major manufacturers of livestock oxidation ditch rotors agree and have replaced all chain drives with belt drives.

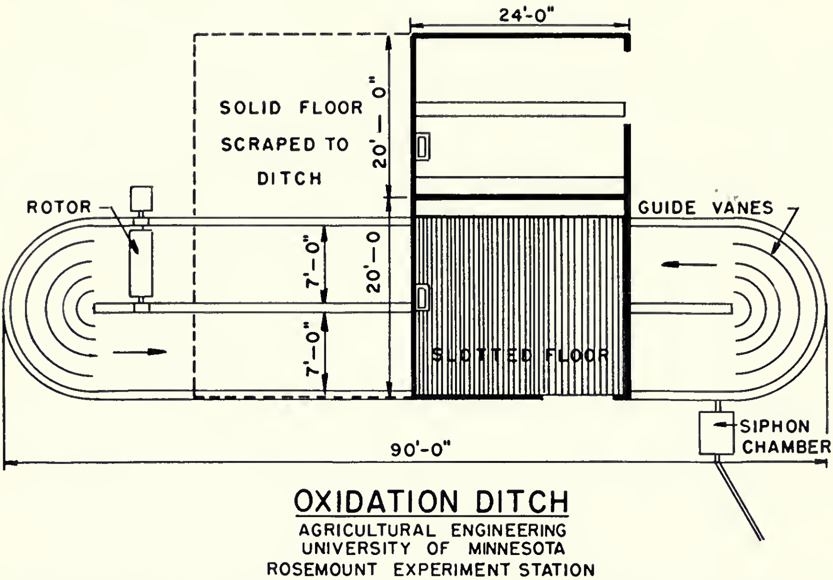
Very little information is available concerning evaporation from an oxidation ditch. An awareness that evaporation occurs is important to the operator so he can determine the volume of ditch overflow and the amount of salt buildup in the ditch. No doubt evaporation is increased by the rotor throwing water into the air, since this will increase contact between air and water; however, the amount of increase is not known.

In a beef confinement building at the University of Minnesota, Moore (1968) found that make-up water had to be added to the oxidation ditch to maintain the desired liquid depth. Those tests were run at ditch volumes of 140 and 210 cubic feet per steer. Assuming a BOD_5 production of 1.3 pounds per steer per day, this indicated 118 and 162 cubic feet of ditch liquid volume per pound of daily BOD_5 respectively. Moore pointed out that the ditch was about 75 percent exposed to the outside atmosphere which possibly affected the evaporation rate.

Overflow did occur from a beef unit at the University of Illinois where a volume of 50 cubic feet per 1,000 pounds of animal was tested (Jones et al., 1969D). McKinney and Bella (1967) reported the need for overflow collection basins for enclosed swine units where volumes of approximately 40 to 50 cubic feet per pound of daily BOD_5 were tested (computed by authors on basis of information given). It seems probable that the amount of liquid lost by evaporation at the rotor will be less than the manure added in most installations. However, since evaporation tends to concentrate solids, make-up water may be necessary to maintain a desired concentration of solids in the ditch.

Effect of Cold Climate

Even though locating the rotor inside causes increased moisture in the building due to evaporation at the rotor, the advantages of this outweigh the disadvantages of having the rotor outside. Where the rotor is exposed to the weather, ice buildup can shut the rotor down during the winter. Rotors can usually run year-round in all climates when placed inside the building. The temperature in the animal unit is usually high enough to prevent any serious icing problems.



Oxidation ditch and buildings for beef cattle at the University of Minnesota, Rosemount Experiment Station. (Fig. 15)

Ice formation in the ditch has been reported in beef operations in Minnesota and Illinois. Studies at Minnesota by Moore et al. (1969) indicate the oxidation ditch system can successfully treat beef cattle waste in climates which experience extended periods of sub-freezing temperatures even with about 75 percent of the ditch exposed to outdoor temperatures (Fig. 15). Foam production was experienced on several occasions in cold weather, and was often great enough to be a limiting parameter. In one field trial in November, December, and January, the monthly average waste temperature in the ditch was 36.8° F. An ice layer up to 1 inch thick formed over part of the ditch. In one part of the ditch the foam was found to freeze and provide an insulation blanket. A high liquid velocity of 1.2 to 2 feet per steer was maintained in the ditch and probably minimized the icing problems.

In a beef cattle unit at the University of Illinois at Urbana, up to two inches of ice have been observed in the channels opposite the rotor when the outside temperature dipped to 5° or 10° F. for a week (Jones et al., 1969D). The velocities in this ditch, although not known exactly, were not as great as in the Minnesota study. The insulation properties of ditch foam that Moore et al. reported were observed in two sections of this ditch.

Besides the mechanical operational problems mentioned above, there is some evidence that biological activity in the ditch is also influenced by cold climates. Pasveer (1954) reports difficulty in developing a good quality of floc in the start-up of a municipal activated sludge plant at temperatures of 7° to 9° C. At this temperature the nitrification process begins slowly if at all. After the temperatures had risen to 13° C., there was no difficulty developing a good quality of floc.

It may be concluded that an oxidation ditch will be able to continue operation throughout the winter months when a small amount of ice is present, although with slightly less efficiency. Efforts should be made in cold climates to construct livestock buildings so they can be closed during the winter, using minimum ventilation. This should conserve the heat produced by the livestock and prevent the oxidation ditch contents from freezing.

Microorganisms, Nitrification, and Denitrification

Researchers have found that oxidation ditches soon establish the needed microbial populations even without seeding. McKinney and Bella (1967) claim the major bacterial group that grows in the activated sludge process is composed of common soil bacteria that easily enter the system, many from the manure itself. They also noted that pathogens will not grow in the oxidation ditch and will eventually die out unless they are in the form of spores which can remain dormant. They found that bacteria are the major microorganisms stabilizing the organic matter in the manure, but protozoa and rotifiers also grow readily. Protozoa are very sensitive to the lack of dissolved oxygen and will die within a few hours under oxygen-deficient conditions. Likewise, stalked ciliates and rotifiers are always present in a well-operated system. They help control the bacterial population and thus are useful in determining the extent of treatment of the waste.

Baxter et al. (1966) found in their oxidation ditch trials with finishing pigs that the biological activity varied widely. The numbers of protozoa present in the supernatant liquor during a period of typical activity were of the order of 20,000 per milliliter. Although the area around the ditches was generally untroubled by insects, there was one short period when a number of hover flies were present and their larvae were later present in the oxidation primary ditch.

Nitrification is important in livestock oxidation ditches because it prevents the release of ammonia into the building atmosphere. Nitrification is the bacterial process of converting ammonia into nitrates, i. e.

$$\text{nitrifying cells} + NH_3 + O_2 \xrightarrow{(\text{via } NO_2)} NO_3 + H_2O + \text{more nitrifying cells}$$

(Simpson, 1960, p. 5). Below a pH of 7 ammonia is in a combined state and not readily released, but ammonia release increases with increases in pH above 7.

Under aerobic conditions the nitrite formers convert ammonia to nitrites. The nitrate formers then oxidize nitrites to nitrates. However, under anaerobic conditions, nitrates and nitrites are both reduced by a process called denitrification which liberates some nitrogen gas to the atmosphere.

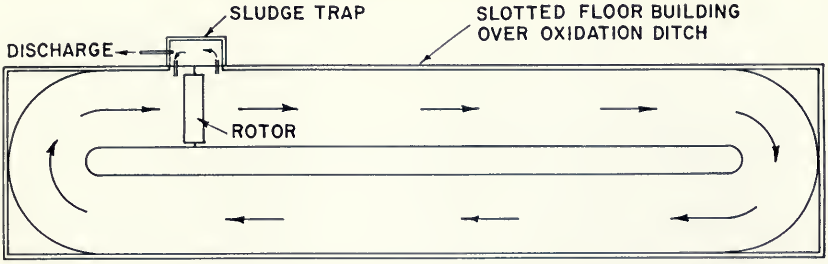
Nitrification-denitrification can occur simultaneously in an oxidation ditch. Nitrification occurs immediately downstream from the rotor where excess dissolved oxygen (D. O.) is present. As the mixed liquor moves around the ditch, D. O. is used up. In the absence of D. O., denitrification can occur and prevent odorous conditions from developing until the nitrates are used up. Of course, it would be a delicate design that would operate in the nitrification-denitrification cycle and have the mixed liquor reach the rotor for re-aeration just as the nitrates are used up. For the most part, oxidation ditches operate with excess D. O. However, Scheltinga (1966) performed experiments in the Netherlands that showed nitrification caused ammonia nitrogen to be oxidized to nitrates, but a lack of nitrates in the effluent indicated that denitrification was occurring.

McKinney and Bella (1967) report from their study in a farrowing house that initially metabolic reactions converted much of the nitrogen in the urine to ammonia, and some ammonia was released to the atmosphere at the rotor since the pH of the mixed liquor was high (above 8). Eventually, nitrification converted the excess ammonia to nitrates in the presence of D. O. The data from the farrowing house indicated that most of the nitrogen in the mixed liquor was tied up as organic nitrogen in the form of microbial cells. A small portion existed in the ammonia form, while a larger portion existed as nitrates. The most important fact, however, was that the majority of the nitrogen was tied up with the solids (sludge).

The release of some ammonia is typical during the first several weeks of operation of a livestock oxidation ditch. This occurs until nitrifying bacteria develop to complete the nitrification process of converting ammonia to nitrates. A mixed-liquor pH slightly above 8 is also typical.

Sludge Accumulation

Not all livestock oxidation ditches have facilities for separate sludge removal and in some cases it is not necessary if sufficient solids are being removed in the overflow. A ditch in a farrowing house located south of Fairbury, Illinois, operated for 2½ years with only mixed liquor overflow. When sampled in July, 1969, the inorganic solids were about 27 percent of



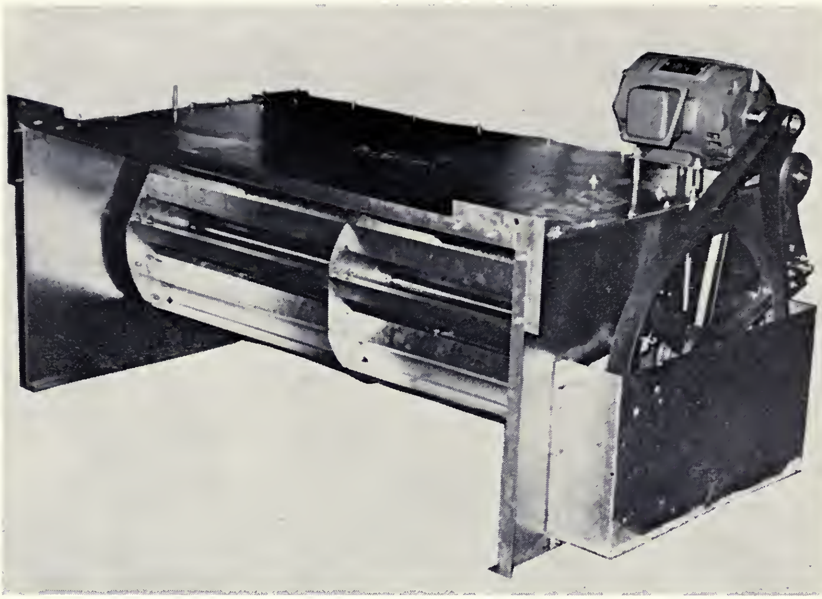
An oxidation ditch with a sludge trap that utilizes the pressure differential of the liquid immediately upstream and downstream from the rotor. (Fig. 16)

the suspended total solids, but the ditch was satisfactory with no odor and a reasonably low BOD_5 (mixed-liquor BOD_5 was 3,000 milligrams per liter).

The addition of a sludge trap should prolong the operation of the system indefinitely. This would reduce the problems of poor treatment and foaming during start-up procedures, since it would be started only once. Sludge traps may be constructed along the side of the ditch channel utilizing the pressure differential of the liquid upstream and downstream from the rotor (Fig. 16). The trap is merely a small compartment through which the flow rate can be controlled. The velocity in the trap is considerably less than the velocity out in the channel so that solids are deposited in the trap.

The particle size and amount of sludge to be removed can be controlled by varying the size of the inlet and outlet of the trap, and therefore varying the velocity through the trap. The sludge collected must be removed fairly often if the unit is to function properly. In municipal plants this is usually accomplished with a small electric pump operated on a time clock to pump the sludge to drying beds several times daily. Something of this nature would be needed in a livestock ditch if it were to be operated for an indefinite period; the procedure, however, could be simplified somewhat, depending on the particular setup. The trap would probably need to be operated only a few days a month since some sludge is being removed continuously with the mixed-liquor effluent. Possibly the inlet and outlet to the trap could be closed and the contents emptied entirely. The sludge could be disposed of in the same manner as the mixed-liquor overflow from the ditch. The mixed-liquor suspended solids concentration in the ditch should be maintained between 10,000 and 20,000 milligrams per liter. Actually, the sludge trap is needed only to maintain this level of floc in the ditch.

There is no research reported in the literature as to the best position along the ditch for the sludge trap. Positions at one end of the channel or

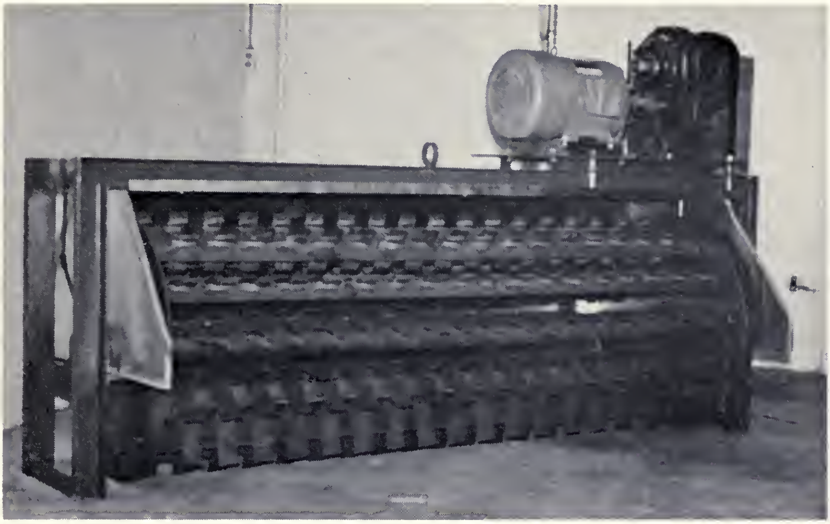


A 16-inch diameter rotor that operates at about 200 r.p.m. (Photo courtesy of Fairfield Engineering and Manufacturing Co.) (Fig. 17)

in the straightaway just after the flow passes the rotor have been used with about equal success. Since the rotor creates an inch or so of hydraulic head, the inlet to the sludge trap can be placed in the ditch just after the flow passes the rotor. If the outlet is then placed on the upstream side of the rotor, flow should occur just opposite in direction to the flow in the ditch proper. The small head will result in a low velocity and will therefore cause settling. A simple method of removing excess solids may be to dilute the ditch volume with water by one-third to one-half when the concentration of solids becomes too high, thus flushing out solids with the overflow.

Dale and Morris (1966) reported that an oxidation ditch operating as a batch system with dairy cattle manure concentrated the minerals and salts in the waste by about 80 to 100 percent. With the exception of nitrogen lost to the air, practically all of the nitrogen, phosphorus, and potassium in the incoming manure is contained in the oxidation ditch effluent (Morris, 1966). It seems probable that the phosphorus and potassium will be concentrated during the treatment process because of the normal evaporation which occurs in an oxidation ditch.

The concentration of nitrogen in the ditch will vary since some ammonia or nitrogen gas may be given off, depending on whether nitrification and denitrification take place in the ditch. Scheltinga (1966) measured the



A 27½-inch-diameter rotor that operates at about 100 r.p.m. Front splash cover removed. (Photo courtesy of Thrive Centers, Inc.) (Fig. 18)

nitrogen in the sludge as 6 to 9 percent of the dry matter. He also measured sludge growth as 18 percent of incoming BOD_5

The percent of ash in a livestock ditch may not be as high as in a municipal ditch because of nonbiodegradable organic matter from undigested feed particles in the livestock waste. However, ash contents from 20 to 25 percent are often obtained. Raw manure usually contains about 15 to 20 percent ash.

Rotors, Oxygenation Capacity, and Liquid Transport

The oxidation ditch uses a cage rotor to aerate and move the liquid around the ditch in a closed circuit so that the liquid passes the rotor at regular intervals to renew its oxygen supplies. Cage-rotor aerators in common use today are from 26 to 36 inches in diameter, although one rotor being produced for agricultural applications is 16 inches in diameter (Fig. 17) (Linn, 1966). Cage rotors usually consist of approximately 12 blades radiating from and rotating about a horizontal axis, and the blades are of a staggered-tooth design, with the teeth on successive blades occupying the voids in the preceding blade (Fig. 18). Blade design, oxygen transfer, and liquid propulsion capabilities vary from rotor to rotor (Agena, 1968). Common rotation speeds are from 60 to 120 r.p.m., although speeds of up to 200 r.p.m. are being used. The length of the rotor required will depend on the required oxygenation rate, the required liquid velocity, and the channel configuration.

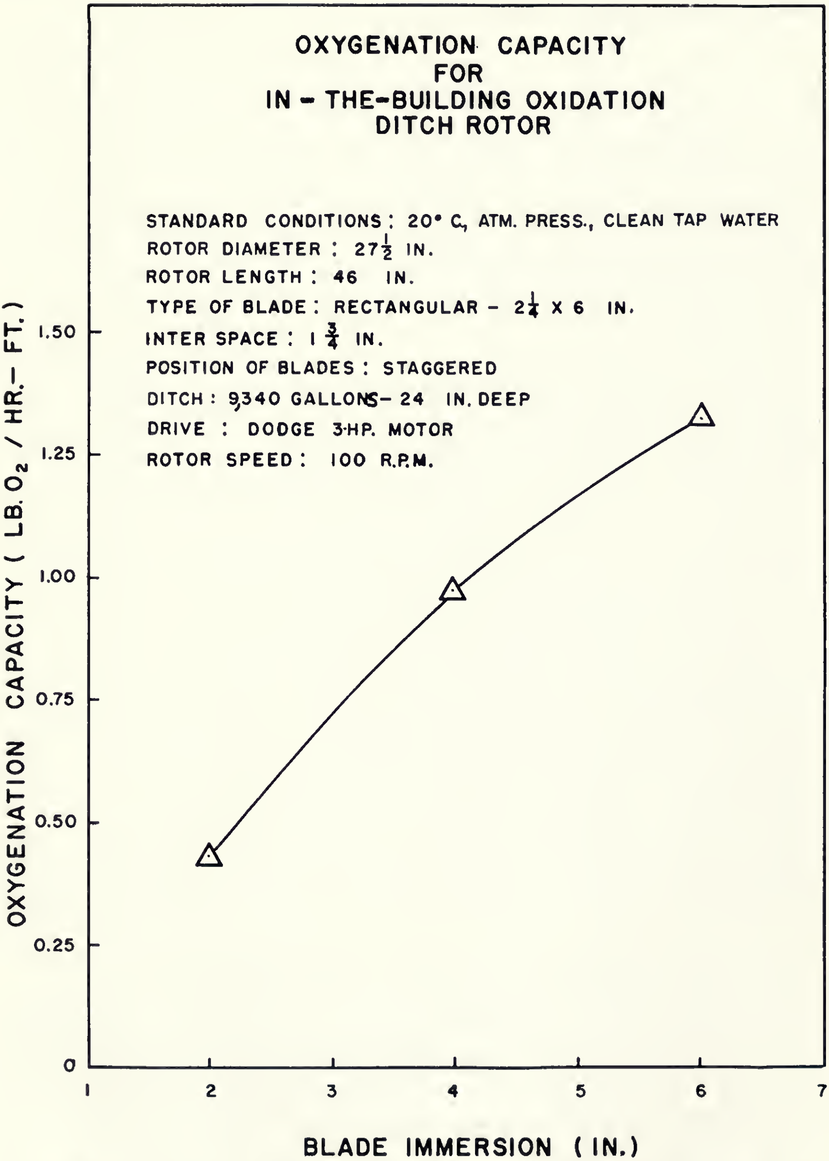
The two main factors affecting oxygenation by rotor aeration in oxidation ditches are rotor speed and rotor immersion. Where a biological mass is present to exert an oxygen demand on the oxygen supply, the rate of recirculation of the liquid is also important.

Five different cage rotors were tested by Jones et al. (1969C) in manure gutters in livestock buildings. The rotors added from 1.3 to 1.9 pounds of oxygen per hour per foot of rotor at 6-inch immersion and 100 r.p.m. operating in a liquid depth of 25 inches. Based on the results of ditch tests in finishing-pig buildings, it was concluded that although immersions as high as 12 inches gave good results in tap water, much less mechanical trouble was experienced when rotor immersion was limited to around 6 inches.

Jones et al. also found that, as a general rule, adequate velocity and oxygenation occurred when the immersion of the aeration rotor in the waste was equal to approximately one-fourth to one-third of the liquid depth. For instance, when the ditch contains 18 inches liquid, the rotor immersion should be 4½ to 6 inches. When the rotor immersion is less than this, some sedimentation may occur in the bottom of the ditch. Therefore, if a 27½-inch-diameter cage rotor can be operated at a maximum immersion of around 8 inches, the maximum liquid depth in the manure pit would be around 32 inches, and preferably less than 24 inches, to maintain proper velocity in the ditch. The actual ditch cross-section can be calculated using the pumping capacity of the rotor.

Jones et al. (1969C) pointed out that rotor aeration efficiency increased almost linearly with rotor speed and rotor immersion. The same type of rotor was tested in two separate ditches having different lengths and widths of channels, but the same depths. They found 30 percent variation in the oxygen-uptake efficiency with the two different ditch configurations tested. Figure 19 shows the oxygenation capacity for a rotor manufactured by Thrive Centers, Inc., and tested in a ditch 5 feet wide and 64 feet long (one way). These values, after being corrected for use in livestock installations, will be used in the design criteria to be presented later in this bulletin.

The main functions of an oxidation ditch rotor in addition to oxygenation is circulation of the liquid to keep solid particles in suspension and to distribute oxygenated liquid throughout the ditch. Liquid transport is often the limiting factor in the design of a rotor, even when adequate oxygen is being added. The liquid velocity required in rotor-aerated ditches depends on the weight, size, and number of waste particles in suspension circulating through the ditch. Velocity is determined by rotor and ditch configurations, liquid properties, ditch lining characteristics, and rotor speed.



Oxygenation capacity of a cage rotor manufactured by Thrive Centers, Inc., operating at standard conditions in tap water (Jones et al., 1969C). (Fig. 19)

Very little research concerning liquid velocity required for solids suspension in oxidation ditches has been published. Pasveer (1963) found that some sludge deposition occurred in municipal ditches when liquid velocities were less than 1 foot per second in the middle of the ditch. On the other hand, Babbit and Baumann (1958) state that a velocity of at least 0.5 feet per second will keep most organic matter in suspension. Knight (1965) found that 0.5 feet per second was adequate to pick up and suspend waste particles lying on the channel bottom. When suspended solid concentrations are as high as 20,000 milligrams per liter in livestock ditches, then a minimum surface velocity of 1.25 feet per second appears necessary (Day and Jones, 1970).

Knight (1965) measured velocities in an oxidation ditch with a trapezoidal cross section 4 feet deep, 4 feet wide at the bottom, and 14 feet wide at the top. The ditch was 105 feet long with an 8-foot-wide median strip. Using a 3-foot-long, 27½-inch-diameter cage rotor, he measured the average liquid velocity in the ditch by averaging four readings taken around the ditch. The average velocity was greater for higher rotor speeds at 3-, 6-, and 9-inch immersion depths. At the 12-inch immersion depth, the average velocity was greater for the lower rotor speed (60 versus 100 r.p.m.).

Velocity transverses throughout the length of an oxidation ditch channel are reported by Nelson et al. (1968). At the rotor discharge, it was found that velocities were as much as six or seven times higher in the top 4 inches of the channel, compared with the bottom 4 inches in a 19-inch depth. However, 24 feet downstream from the rotor the velocities were essentially uniform from within 2 inches of the channel floor to the surface. Immediately after the turn, velocities at the center and outer portion of the channel, with respect to the turn, were five to six times greater than velocities at the inside of the channel. These measurements indicated that sludge solids may accumulate in critical zones after a turn even when mean velocity is adequate to transport the sludge.

The liquid flow in an oxidation ditch is produced by inertia and viscous forces by the rotor and not by gravitational forces. Since the velocity of the flow is dependent upon friction in the ditch, efforts should be made where possible to eliminate or reduce friction. Most ditch walls in livestock buildings will be smooth concrete. When designing an oxidation ditch, some thought should be given to using a wider median strip where feasible to eliminate the sharp 180-degree turn commonly used. Straight channels should always be used under the length of the building with no jogs or turns in the channel to cause friction and turbulence, both of which act to decrease the liquid velocity.

In a model study at Oklahoma State University, Agena (1968) found that, providing all other pertinent quantities were held constant, the mean ditch liquid velocity:

1. Increased as rotor speed increased, with the rate of increase for a given speed change being greater at lower speeds than at higher speeds.

2. Increased as paddle finger width decreased (while the inner-space remained the same), with the rate of increase for a given change in finger width being greater at smaller finger widths than at larger finger widths.

3. Increased as immersion depth increased, with the rate of increase for a given change in immersion depth being greater at low immersions than at high immersions.

4. Increased as liquid depth decreased, with the rate of increase for a given change in depth being greater at small depths than at large depths.

The uniformity of flow across a section of that channel not containing the rotor decreased as the channel length decreased.

Design and Operational Criteria

McKinney and Bella (1967) discussed rotor design in an oxidation ditch with respect to both liquid transport and aeration. They concluded that only the fraction of water actually in contact with the rotor blade is saturated with oxygen as a given volume of liquid passes the rotor. Thus, in a ditch with 14 inches of liquid and 3-inch rotor immersion, only 21 percent of the flow is saturated. The turbulence created by the rotor helps mix the oxygenated liquid with the non-oxygenated liquid so that the mixed liquor in front of the rotor has a uniform oxygen content within a relatively short distance. In designing oxidation ditches for livestock confinement units, the oxygenation and pumpage by the rotor must be balanced against the organic loading and the animal pen area above the slats.

McKinney and Bella used the following example to illustrate their point. In a farrowing house with a daily loading of 130 pounds of ultimate BOD and with complete nitrification, the length of travel around the ditch was 300 feet. With a one-foot-per-second ditch velocity, a single trip would take 5 minutes. This is an oxygen demand of 0.45 pounds of oxygen in 5 minutes. The fraction of waste volume receiving oxygen would be calculated from the ratio of rotor submergence to liquid depth. The weight of water in the system can be calculated from the area of the ditch, liquid weight, and the specific weight of water. Multiplying all of these terms by the oxygen of saturation in pounds per 10^6, or milligrams per liter, yields the quantity of oxygen in pounds:

$$\frac{d_r}{D}(2{,}470D)(6{,}214)(7.0/10^6) = 0.45, \text{ where}$$

d_r is the rotor immersion in feet or inches,

D is the ditch liquid depth in feet,

62.4 is the liquid density in pounds per cubic foot,

7.0 is the saturation value of waste, assuming 80 percent of the saturation value for tap water in milligrams of oxygen per liter of wastes,

0.45 is the pounds of oxygen that must be added to the waste in the time required for one complete trip around the ditch, and

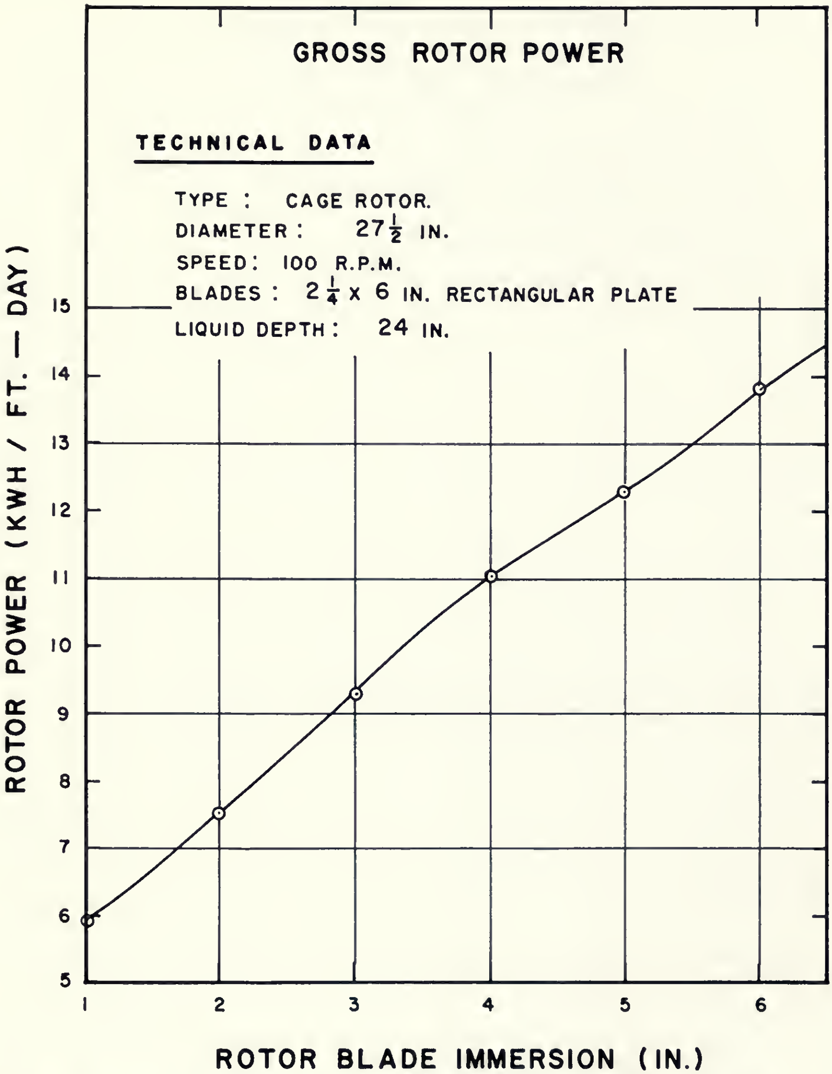
2,570 is the surface area of the ditch in square feet.

Upon solving the equation, d_r is equal to 5 inches. Based on ditch observations, McKinney and Bella state that a 70-r.p.m. rotor with 3-inch immersion can pump 1.2 cubic feet per second of waste per foot of rotor. They believe that the volume of flow can be increased proportionately by increasing the rotor speed to at least 100 r.p.m. or by increasing the depth of rotor immersion to about 9 inches (Knight, 1965). Therefore, using a d_r of 5 inches, the rotor would have a pumpage of about 2 cubic feet per second per foot of rotor. With a 1-foot per second velocity, this will produce a liquid depth of 24 inches in the example above.

McKinney and Bella (1967) note that it is not realistic to design on the maximum possible oxygen demand, including nitrification. For practical purposes, it is possible to design on the basis of carbonaceous BOD_5. In the example above, this is only 0.24 pound of oxygen supplied during each 5-minute loop. The rotor immersion in this case would need to be 2.7 inches with a liquid depth of 13½ inches. This was verified in a field trial with 3-inch immersion and 14-inch depth with good results. The building was actually loaded to only 80 percent of capacity in this trial so it might be necessary in practice to modify this design slightly.

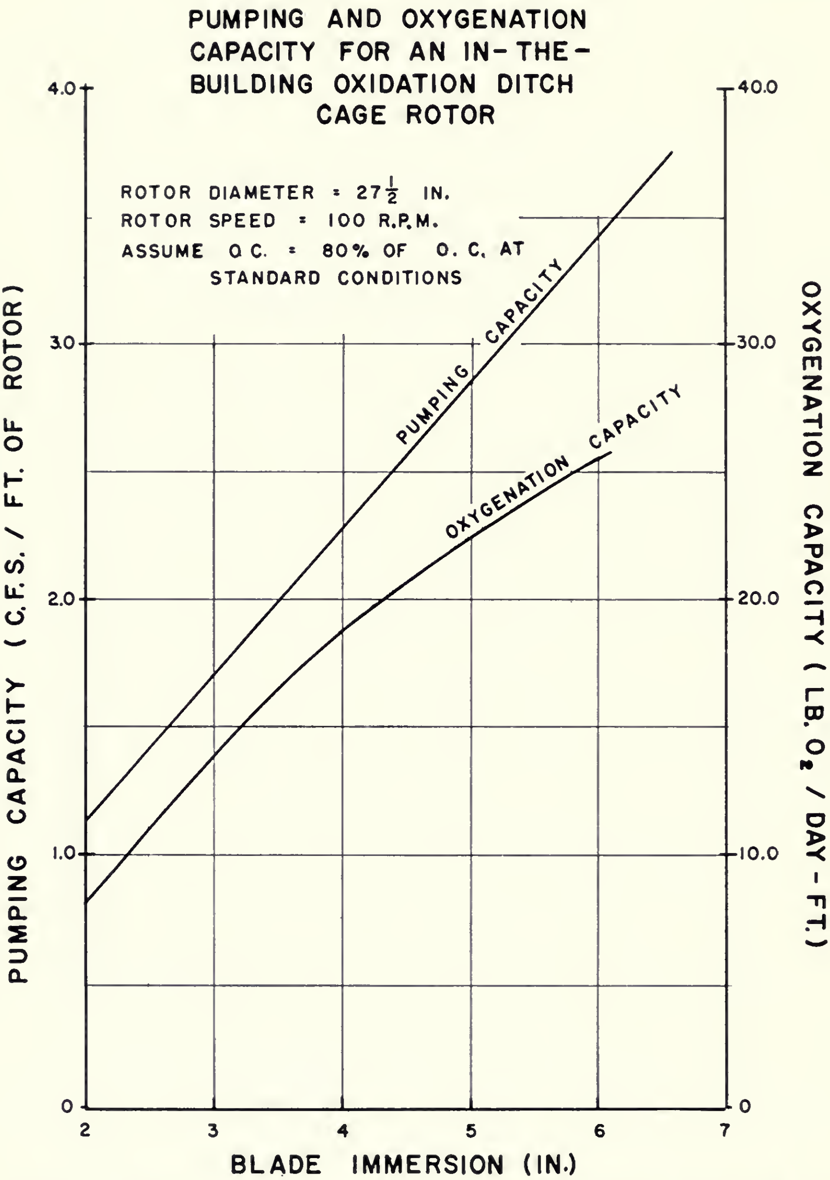
Livestock waste added to oxidation ditches is usually undiluted and does not contain wash water or bedding. It will be assumed that this is the case for the ditch design calculations presented later. It must be kept in mind that there are only limited data available on the operation of livestock oxidation ditches. The general design procedures to be followed here will be based on experience from existing operations. Results from three oxidation ditch studies with swine and two ditch studies with beef cattle will be used as a basis for the design criteria.[1] Table 1 presents the amount and composition of the wastes from common farm animals. These

[1] These studies were mentioned earlier: Baxter et al. (1966); McKinney and Bella (1967); Jones et al. (1969A); Jones et al. (1969D); and Moore et al. (1969).



Typical operating costs of a cage rotor operating in a livestock oxidation ditch, based on 2 cents per KWH (Day and Jones, 1970). (Fig. 20)

values will be used in the design procedure. All designs are based on daily BOD_5 production. An oxidation ditch volume of 30 cubic feet of mixed-liquor volume per pound of daily BOD_5 is used for livestock ditch design. This results in detention times of 40 to 80 days. With these loading rates and starting with tap water in the ditch, one could expect to operate a



Typical oxygenation and pumping capacities of a cage rotor operating in a livestock oxidation ditch. The oxygenation capacity curve is 80 percent of the tested performance of the rotor in clean water corrected to standard temperature and pressure (Jones et al., 1969C). The pumping capacity curve was calculated using data reported by McKinney and Bella (1967). (Fig. 21)

continuous-overflow oxidation ditch for an indefinite length of time if the volatile suspended solids in the ditch were kept at the 20,000-milligrams-per-liter level by the addition of water as required to flush out solids.

Two requirements must be met when selecting a rotor for a specific livestock building: the oxygenation capacity must be equal to twice the daily BOD_5 added, and there must be a pumping capacity capable of moving the waste at an average minimum surface velocity of 1.25 feet per second. The rotor manufacturer may be able to supply oxygenation, pumping, and power requirement values for his rotor, but the values presented in Figures 20 and 21 for a cage rotor (27½-inch diameter operated at 100 r.p.m.) may be used in lieu of this.

The oxidation ditch design criteria can be summarized as:

1. Minimum liquid volume per pound of daily BOD_5 loading equal to 30 cubic feet.

2. Rotor oxygenation capacity equal to twice the daily BOD_5 loading.

3. Rotor pumpage sufficient to maintain a liquid velocity of 1.25 feet per second.

4. Rotor operating power requirement is approximately 1 KWH per pound of daily BOD_5 loading.

5. Evaporation losses should be made up with tap water to maintain the required liquid depth. This may be more of a problem with sheep and poultry wastes because the moisture contents of these wastes are considerably less than swine and cattle wastes (see Table 1).

6. Volatile suspended solids level in the ditch of around 20,000 milligrams per liter. This is not an absolute value, but rather a recommended average maximum concentration depending upon how the effluent is handled.

7. The maximum ditch distance between rotors should be about 350 feet.

8. Freeboard clearance between the top of the liquid and the bottom of the slats or beams should be equal to at least 1 foot or ½ of the liquid depth, whichever is larger.

Steps for Designing an In-The-Building Oxidation Ditch

1. Determine the maximum daily BOD_5 loading, use Table 1 if values for the particular wastes are unknown.

2. Compute the ditch volume by multiplying the approximate loading rate of 30 cubic feet per pound of BOD_5 by the total daily BOD_5.

3. Determine the ditch liquid depth. The surface area of the pit will be determined from the floor plan of the building and the penned area. To maintain low-odor conditions, it is desirable to use the minimum floor

Table 2. — Design Recommendations for In-the-Building Oxidation Ditches

Animal unit	Weight, lb. per unit	Daily BOD_5, lb. per unit[a]	Daily req. oxygenation cap., lb. per unit[b]	No. of animals per ft. of rotor, units per foot[c]	Ditch vol., cubic ft. per unit[d]	Daily power reqmt., KWH per unit[e]	Daily cost, cents per unit[f]
Swine							
Sow with litter........	375	.79	1.58	16	23.7	.83	1.66
Growing pig..........	65	.14	.28	91	4.2	.15	.30
Finishing hog.........	150	.32	.62	41	9.6	.33	.66
Dairy Cattle							
Dairy cow............	1,300	2.21	4.42	6	66	2.33	4.66
Beef Cattle							
Beef feeder...........	900	1.35	2.70	10	40	1.42	2.84
Sheep							
Sheep feeder..........	75	.053	.11	230	1.6	.06	.12
Poultry							
Poultry feeder.........	4.5	.0198	.0396	650	.6	.021	.042

[a] From Table 1. Use specific production data when known.
[b] Twice the daily BOD_5.
[c] Based on 25.5 pounds of O_2 per foot of rotor per day (Fig. 21 at 6-inch immersion).
[d] Based on 30 cubic feet per pound of daily BOD_5.
[e] Based on 1.9 pounds of O_2 per KWH (Figs. 20 and 21 at 6-inch immersion).
[f] Based on electricity at 2 cents per KWH.

space necessary for each animal and to use totally slotted floors. The ditch width and the ditch length will also be determined from the building floor plan and pen layout. This leaves one parameter to be determined — the ditch depth. The depth can be determined by dividing the ditch volume by the surface area of the ditch.

4. Determine the rotor length required for oxygenation. Using the blade immersion at which one wishes to operate, find the daily oxygenation capacity per foot of rotor (Figure 21). To minimize capital expenditures, use the deepest blade immersion recommended for the rotor. Since the daily oxygenation capacity must be equal to twice the daily BOD_5, multiply the daily BOD_5 by two and divide this by the daily oxygenation capacity per foot of rotor to obtain length of rotor needed.

5. Make certain the rotor immersion depth used for oxygenation is sufficient for pumpage. To determine the blade immersion required for pumping, multiply the ditch cross-sectional area by a minimum velocity of 1.25 feet per second and divide by the length of rotor to be used. The maximum distance between rotors should not exceed 350 feet. The blade immersion required for this much pumpage can then be found from Figure 21. The blade immersion required for oxygenation (step 4) and the immersion

required for pumpage should then be compared and the larger value should be used.

6. Check power requirements and operating costs.

7. A method of disposing of the mixed-liquor overflow must be selected. Direct discharge by gravity into an aerobic lagoon is probably best for operator convenience. Other alternatives are hauling directly from the ditch or from an overflow holding tank.

An example follows to help clarify the design procedure.

Example: Oxidation Ditch for Swine

Given. A building with slotted floors to house 500 finishing hogs (maximum average weight of 150 pounds).

Problem. Specify an in-the-building oxidation ditch to treat the waste and eliminate objectionable odors. Assume the ditch is operated at a constant liquid depth by using an overflow.

Solution. Experience has shown that there must be a totally slotted floor to produce the needed ditch volume with the shallow depth that is required for circulation to prevent settling. Use a floor area of 6 square feet per finishing pig (Muehling, 1969). Assume a slat nominal length of 8 feet and a ditch width of 7.5 feet. Thus, a ditch length of 0.8 feet will be needed for each pig.

Step 1. Daily BOD_5 loading (assume as in Table 1) = 500 hogs × 150 lb. each $\times \frac{2.1 \text{ lb. } BOD_5}{1{,}000 \text{ lb. Hogs}}$ = 158 pounds of daily BOD_5.

Step 2. Ditch liquid volume = 158 lb. $BOD_5 \times \frac{30 \text{ cu. ft.}}{\text{lb. } BOD_5}$ = 4,740 cubic feet.

Step 3. Total ditch length = $\frac{0.8 \text{ ft.}}{\text{hog}}$ × 500 hogs = 400 ft. Assume the building is 32 feet wide and 100 feet long with two complete ditch circuits. The surface area of the ditches down and back, will be 4 × 100 feet × 7.5 feet = 3,000 square feet. The ditch depths will therefore be:

$$\frac{4{,}740 \text{ cu. ft.}}{3{,}000 \text{ sq. ft.}} = 1.6 \text{ feet or 19 inches.}$$

Step 4. Assuming an operating rotor blade immersion depth of 6 inches (Fig. 21), the daily oxygenation capacity per foot of rotor is 25.5 pounds of O_2 per day per foot. The length of rotor required will then be:

$$\frac{158 \text{ lb. } BOD_5/\text{day} \times 2}{25.5 \text{ lb. } O_2/\text{day/ft.}} = 2.4 \text{ feet.}$$

Use two rotors (one in each circuit) about 8 feet long, assume the actual blade length of each is 7 feet.

Oxygenation required per foot of actual rotor length is:

$$\frac{158\text{ lb. BOD}_5\text{/day} \times 2}{14\text{ ft.}} = 22.6\text{ lb. O}_2\text{ per day per foot.}$$

Rotor blade immersion depth, from Figure 21, should be about 5 inches.

Step 5. The ditch liquid cross-section area is 1.6 feet × 7.5 feet = 12 square feet and required flow rate will be:

$$1.25\text{ f.p.s.} \times 12\text{ sq. ft.} = 15\text{ c.f.s.}$$

The rotor pumping capacity required is:

$$\frac{15.0\text{ c.f.s.}}{7\text{ ft.}} = 2.14\,\frac{\text{c.f.s.}}{\text{ft.}}$$

From Figure 21 the rotor blade immersion depth required for the pumping capacity in this problem is 3.7 inches. However, a rotor blade immersion depth of 5 inches is required for oxygenation, so use a 5-inch rotor blade immersion depth, the greater of the two requirements.

Step 6. Power requirements for the rotors are approximately:

$$\frac{1\text{ KWH}}{\text{lb. BOD}_5} \times \frac{158\text{ lb. BOD}_5}{\text{day}} \times \frac{\text{day}}{24\text{ hr.}} = 6.6\text{ KW.}$$

A motor with a rating of 5 horsepower would probably be used on each rotor. Operating power cost (Figure 20) is:

$$\frac{12.2\text{ KWH}}{\text{ft.-day}} \times 2 \times 7\text{ ft.} \times \frac{2¢}{\text{KWH}} = \$3.42\text{ per day.}$$

Step 7. Assume the mixed liquor will overflow into an oxidation pond. The daily loading is assumed to be 10 percent of the daily loading of the ditch, i.e., assume 90 percent BOD_5 reduction in the ditch. From Table 3, lagoon volume for an oxidation pond is (using 10 percent of tabulated value):

$$10\% \times \frac{8\text{ ft.}^3}{\text{lb. of hog}} \times 500\ (150\text{ lb. hogs}) = 60{,}000\text{ ft.}^3.$$

At 4 feet deep, this is 0.34 acre. This oxidation pond sizing is for ideal conditions. The size should be increased accordingly for non-uniform loading, freezing conditions, and if the BOD_5 is reduced less than 90 percent in the oxidation ditch (an alternative would be to use an aerated lagoon). Surplus water and sludge can be removed as required by irrigating when convenient.

Table 2 was computed for use in estimating design requirements for livestock oxidation ditches using BOD_5 production data from Table 1.

Specific BOD_5 production data should be used when known. Note, these design recommendations have been verified in laboratory and field experiments for finishing hogs only. The other recommendations are extrapolated from hog research data, but should serve as a guide until further data are obtained.

Professional help should be obtained when designing oxidation ditches. Manufacturers of rotors for livestock ditches are a source of such help.

AEROBIC LAGOONS

Aerobic lagoons may be divided into two classifications, dependent upon the method of aeration: oxidation ponds (naturally aerated lagoons), and aerated lagoons (mechanically aerated lagoons). It is generally assumed that both will be aerobic and therefore will not produce highly odorous gases. However, this assumption is based on the premise that sufficient oxygen will be supplied to the system to insure the maintenance of an aerobic condition.

The reactions that take place in an aerated lagoon are similar to those in the oxidation ditch. The biodegradable portion of the organic wastes is stabilized and the sludge is mineralized to such an extent that objectionable odors are eliminated. The main differences between the aerated lagoon and the oxidation ditch may be in the size and shape, and in the temperature variations, since the lagoon is not likely to be enclosed. An aerated lagoon may have essentially the same detention time as an oxidation ditch of the same size. An oxidation pond would have a considerably larger surface area than either the oxidation ditch or the aerated lagoon. The temperature of a lagoon or an oxidation ditch located outside is likely to be near the average air temperature.

The exact waste disposal procedure one wishes to use determines the final layout of a lagoon system. If a mechanically aerated lagoon is used to take the place of an oxidation ditch, it can be operated in a similar manner with the same approximate sizes or detention times. In such a case, a second lagoon, probably an oxidation pond, may be required to receive overflow from the aerated lagoon. The second lagoon may be operated in a similar manner as those receiving overflow from an oxidation ditch. Liquids may be discharged in the usual manner with solids dried on a sand bed. However, a system of irrigating mixed liquors and suspended solids on adjacent cropland has been found to be highly successful at Purdue University. This desludges the lagoon and removes excess liquids, thereby providing space for additional livestock wastes. Evaporation from lagoons in the Illinois and Indiana areas is about equal to the rainfall. Therefore, lagoons cannot be expected to "dry out" over a period

of time. Also, excess liquids must be removed by discharging into an acceptable channel or irrigating onto some acceptable land area.

If one is going to use a lagoon system for the disposal of livestock wastes, consideration must be given to the entire system. Some means of routine flushing of the wastes into the lagoon must be provided. In most installations, daily flushing is mandatory, and more frequent automatic flushing may be required to prevent odor production that results from shock loads. When adequate water supplies are not available for channel or floor flushing, arrangements may be made to use the water from the lagoon. Drainage from the collection channels to the lagoon should be by gravity if at all possible. If this is not possible, all channels and floors should be drained to a centrally located sump provided with an automatically activated pump which discharges into the lagoon.

The actual layout of the lagoon is variable and would depend in part on the available area. A round or oblong shape, depending on the aeration method to be used, would be the most desirable for raw waste distribution. The lagoon should probably be located near the livestock area to limit piping maintenance and problems of stoppages.

Another factor that should be considered in the location of the lagoon is the soil characteristics. The lagoon should be located in a tight, preferably clay, soil to prevent leakage and subsurface water contamination. If such a soil is not available, arrangements should be made to waterproof the lagoon. Sodium carbonate mixed with clay soil has been found to be a good waterproofing mix. The use of soil cement or the installation of a plastic lining are also accepted practices in lagoons.

Loading of the lagoon is a critical factor in the maintenance of proper operation. Unusually large loads (slugs) of waste materials change the pH and other environmental factors, deplete the dissolved oxygen, and often result in what is called a "shock load." The digestion process is therefore upset and the lagoon does not function as it should. The most desirable loading system is one that feeds the lagoon (bacteria) with a steady, continuous feed in such a quantity so as to balance the feed, the microflora, and the oxygenation capacity. The minimum loading times per day is about two for satisfactory operation, but more frequent feeding is desirable.

Oxidation Ponds

An oxidation pond (naturally aerated lagoon) is usually a shallow basin 3 to 5 feet deep for the purpose of treating sewage or other waste water by storage under climatic conditions (warmth, light, and wind) that promote the introduction of atmospheric oxygen and that favor the growth of algae. Bacterial decomposition of the wastes releases

Table 3. — Volume Required for Oxidation Ponds Receiving Raw Livestock Wastes[a] (Recommended Depth: 3 to 5 Feet)

Livestock	Volume for each pound of livestock
Poultry	17 cubic feet
Swine	8 cubic feet
Dairy cattle	7 cubic feet
Beef cattle	6 cubic feet

[a] Computed using daily BOD_5 productions from Table 1 and a loading of 45 pounds of daily BOD_5 per surface acre.

carbon dioxide which promotes heavy growths of algae. Ammonia and other plant-growth substances are used up by the algae and dissolved oxygen is kept at a high level. The driving force in this type of self-purification is photosynthesis, supported by a symbiosis between saprophytic bacteria and algae.

If oxidation ponds are properly constructed and hold the wastes for a sufficient time, a good destruction of coliform organisms and a satisfactory reduction of BOD_5 occur. The effluent is usually high in dissolved oxygen; often supersaturated during the daytime. Loadings in the vicinity of 45 pounds of BOD_5 per acre are generally acceptable (Symons and McKinney, 1958). Oxidation ponds may require cleaning after an interval of several years and weeds must be kept under control.

For livestock waste treatment, some modifications have been made in the recommended loading rates. Clark (1965) suggests that an acre of lagoon 5 feet to 6 feet deep would handle the wastes from 275 to 300 head of 150-pound feeder pigs. This is a loading rate of about 96 to 105 pounds of BOD_5 per day per acre. If the lagoon is 5 feet deep, this is an average of slightly less than 750 cubic feet per hog or about 5 cubic feet of capacity per pound of hog. However, the present recommendations of the Midwest Plan Service (Lagoon Manure Disposal, 1966) is 2 cubic feet per pound of swine for an anaerobic lagoon with no particular limits on the depth. In much of the Midwest, Clark's early recommendations would likely not provide an aerobic system if the lagoon receives all the wastes.

Table 3 gives recommended sizes for naturally aerobic lagoons for livestock. The size can be reduced by removing the settleable solids, using a settling basin or septic tank. It is estimated that up to one-half of the BOD_5 might be removed in a settling tank which would proportionately reduce the size of the lagoon or permit it to handle the waste from more livestock.

Because of the large surface area required, oxidation ponds have not

Table 4. — Volume Required for Mechanically Aerated Lagoons Receiving Raw Livestock Wastes (800 Days Detention Time)

Livestock	Volume for each pound of livestock
Poultry	.75 cubic foot
Swine	1.00 cubic foot
Dairy cattle	1.25 cubic feet
Beef cattle	.75 cubic foot

found favor with livestock producers. Their use has been essentially limited to receiving effluent from anaerobic lagoons and other treatment units. In this application, they provide additional treatment for the wastes with a reduced surface area. Some producers have used oxidation ponds to store anaerobic lagoon effluent for eventual disposal by land application.

Aerated Lagoons

In aerated lagoons, oxygen is furnished by means of some type of mechanism that "beats" or blows air into the water with a portion of the oxygen being dissolved. The lagoon is therefore not dependent on the wind or algae growth for the oxygen supply. Therefore, the design criteria (surface dimensions and depth) differ greatly from those of the oxidation pond.

Satisfactory aerobic treatment of livestock wastes has been obtained in aerated lagoons that have a volume of approximately 50 times the daily manure production. However, if the aerated lagoon is considered as a final or long-time storage of the waste residues, a much larger size is needed. If one intends to de-sludge the lagoon yearly or more often, the size may be reduced. Otherwise a detention time of two to three years is recommended (Table 4).

For continuous operation, a mechanical aerator that will provide an oxygenation capacity of 1.5 times the total daily BOD_5 loading is the minimum size recommended to obtain stabilization. If the operation is to be intermittent (off in the extreme cold months such as December, January, and February), the aerator should have an oxygenation capacity of at least twice the daily BOD_5 loading.

For complete odor control, the aeration (oxygen) requirements are not greatly different from those required for stabilization. However, for partial odor control, an oxygen supply of one-third to one-half the daily BOD_5 will be of some benefit. The low rate of aeration stops the release of many of the volatile acids and the accompanying gases such as hydrogen sulfide and some of the mercaptan gases (Ludington et al., 1969). Generally

ammonia production is not stopped and the odor is still detectable. Although it is not clearly understood, the pH is raised with the low aeration rate and this prevents the release of H_2S. However, ammonia release will be increased.

There are numerous methods for aerating lagoons. However, it is not clear which may be the "best." Floating aerators appear to be satisfactory, but other schemes such as compressed air entering through diffusers (perforated pipes), rotating aerators, and rotary blowers may also work satisfactorily. Some manufacturers of floating aerators guarantee an oxygenation capacity of about 3.2 pounds per horsepower hour at a standard condition of 20° C. in clean water at a given percent of saturation of dissolved oxygen in the water. An oxygenation capacity of this quantity is probably the maximum that can be expected, but in many cases, it may be lower.

The mechanically aerated lagoon should be aerated continuously, because aerobic conditions thrive when oxygen is freely available. When oxygen is not available, the aerobic bacteria are inhibited in their growth and reproduction with the result that anaerobic conditions develop. If this condition persists, the whole system is "upset" and considerable time is required to return to the normal aerobic condition once the aerator is restarted. Part of this problem comes from the fact that a large storage of dissolved oxygen in water is impossible, since the oxygen saturation range is only about 6 to 9 milligrams of oxygen per liter of water. After saturation, additional oxygen is not held by the solution and further aeration is of little use and would add unnecessary expense. The ideal system then is one in which oxygen is being supplied at a rate equal to the oxygen demand.

The rate of decomposition is slowed as the temperature decreases. It appears that below 40° F. bacterial action is greatly reduced and below 35° F. there is little activity. On this basis, it appears that little decomposition is accomplished by operating exposed aerators in extremely cold weather. However, the aerator should be started as soon as the temperature begins to warm up in the spring so that aerobic bacterial action can be reestablished. Some objectionable odors can be expected during the startup period.

A two-horsepower floating aerator operating in a 6-foot deep lagoon at the Purdue University Dairy Farm did not freeze up during the winter of 1967-68, but there was little evidence of bacterial activity during that period. Ice piled up around the aerator and its efficiency probably was impaired. A deeper lagoon would probably have helped, but the evaporative cooling, as well as the other heat losses, would have lowered the temperature below 35° F. A similar situation was observed at the University of Illinois during the 1968-69 winter.

Removal of Sludge and Surface Water

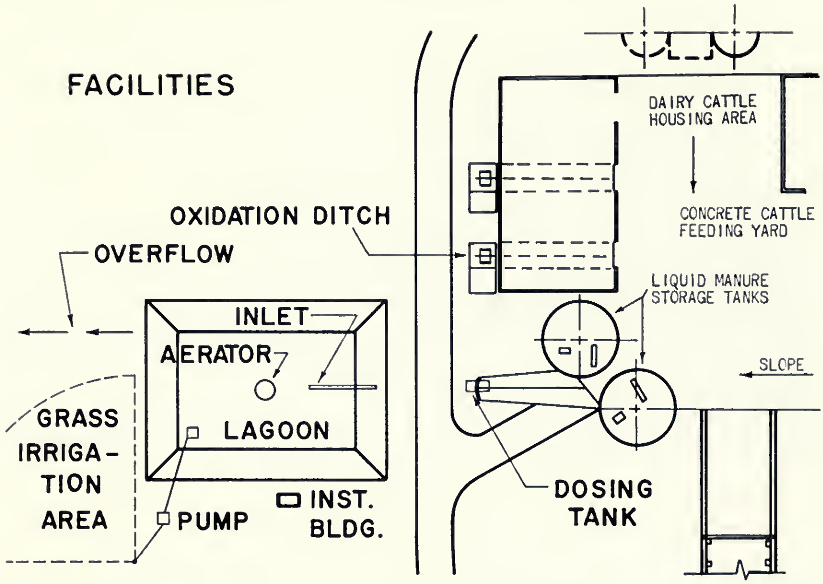
Considerable decomposition of the organic solids occurs in aerobic lagoons. Although the rate of decomposition is greatly reduced after some 30 days, decomposition does continue, and it is believed that in a period of 1½ to 2 years the volatile solids may be reduced by as much as 60 to 70 percent.

However, even with good degradation, solids (sludge) will eventually build up in the lagoon until removal is necessary. The rate of sludge buildup depends upon the size of the lagoon in relation to the manure added and the breakdown that occurs. This sludge will contain considerable nutrients and may be removed and applied directly on cropland if desired. Otherwise, it may have to be discharged onto a sand or gravel bed for de-watering and drying. Late fall appears to be a good time for removal of sludge from lagoons. The solids are the most stabilized at that time and the odors are low if the lagoon has been well aerated during the previous seven to eight months. A vacuum pump or other sewage pump will remove sludge from the bottom of a lagoon. If the sludge has compacted too much, an auger may have to be used for stirring and mixing.

When disposal of excess water is needed, irrigating mixed liquor from an aerobic lagoon has worked satisfactorily (Dale et al., 1969). Sludge buildup was not a problem, since suspended solids were removed by the irrigation unit. However, if surplus water is not a problem the non-overflow lagoon with regular sludge removal may be satisfactory.

The continued operation of a system requires that the mixed-liquor total solids content not exceed some maximum value. It is not known at the present time just what this value is. In a mechanically aerated lagoon, the aeration device can only operate effectively in liquid of a certain consistency. In an oxidation pond, a solids concentration that is too high will result in settling and anaerobic conditions. Also, the irrigation system can handle only a limited amount of solid material. One might estimate the upper limit of total solids to be about 20,000 to 30,000 milligrams per liter, or 2 to 3 percent in the completely mixed system. Additional water, if available, may be helpful in reducing solids concentrations. Degradation can reduce the total solids by 20 to 40 percent, which should provide a mixed liquor of not more than 2 to 3 percent solids content. This material containing 2 percent of solids can be removed by irrigation, thus leaving only a small part that may settle to the bottom of the lagoon.

For a mechanically aerated lagoon, some hydrolysis and anaerobic decomposition may take place in the bottom of the lagoon, thus reducing some of the solids. The products of anerobic decomposition are then further degraded in the upper aerobic levels of the lagoon. This process has



Layout of facilities at the Purdue University dairy farm. (Fig. 22)

been referred to as a two-stage lagoon, anaerobic in the lower portion and aerobic in the upper portion.

AN AERATED LAGOON SYSTEM WITH IRRIGATION AN EXPERIMENTAL STUDY

When excess water must be removed from a mechanically aerated lagoon, irrigating the mixed liquor seems desirable. Sludge build-up is not a problem since suspended solids are removed by the irrigating unit. Essentially all criteria for operation of the aerated lagoon apply to a lagoon operated in this manner. For example, the loading rates, temperature effects, and the need for continuous operation are no different. The main difference is in the de-sludging which is accomplished by the irrigation system. As a check on this system, an experiment was performed by researchers at Purdue University (Dale et al., 1969). A similar study using anaerobic lagoon effluent was conducted at Iowa State University by Koelliker and Miner (1969).

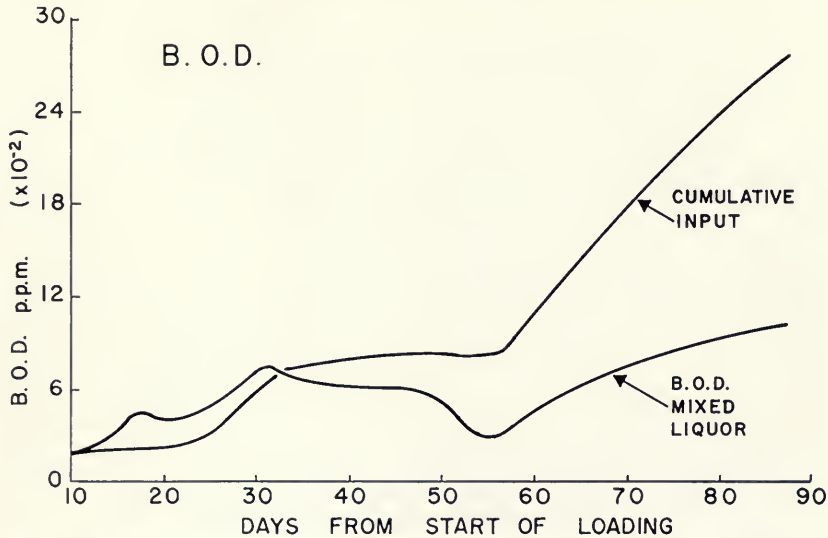
A lagoon studied at the Purdue Dairy Center had received runoff from a dairy cattle concrete feeding floor for approximately 12 months prior to the 87-day study. The floating aerator had been in intermittent operation during the spring and summer prior to the start of the test. The

Mechanically aerated lagoon with the dairy housing in the background. (Fig. 23)

lagoon had an average volume of 18,000 cubic feet and was approximately six feet deep.

The aerator was a nominal 2 horsepower for the initial period to day 44 and 5 horsepower from that day to the end. Effluent from this lagoon was withdrawn with a centrifugal pump and applied to adjacent land through an irrigation sprinkler system. A plan of the dairy layout used in this study is shown in Figure 22. Pictures of the lagoon and irrigation system in operation are shown in Figures 23 and 24.

Irrigation system in operation adjacent to the mechanically aerated lagoon. (Fig. 24)



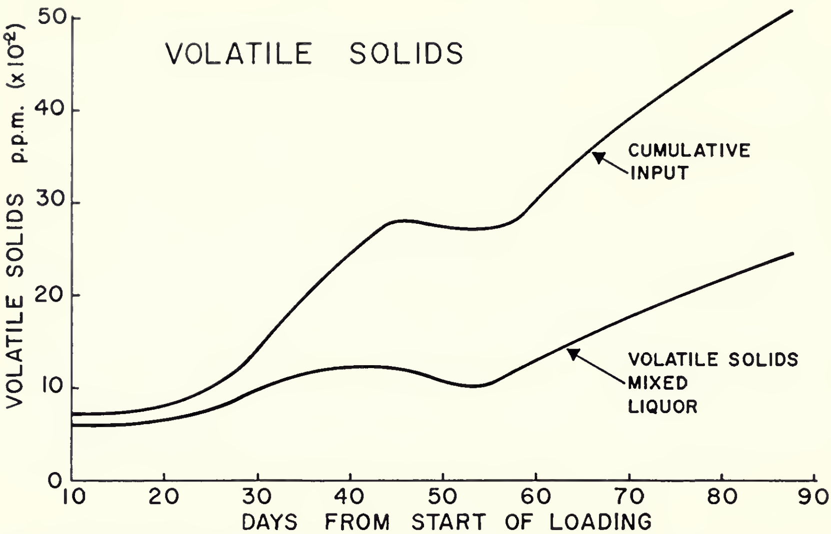
BOD_5 of the lagoon mixed liquor and cumulative (BOD_5 input minus BOD_5 irrigated). (Fig. 25)

Based on laboratory tests, manure having BOD_5 of approximately 75 pounds and a chemical oxygen demand (COD) of approximately 225 pounds was placed into the lagoon daily for the last 30 days. The initial reaction after the daily loading was a rapid drop in the dissolved oxygen level in the lagoon within 15 to 20 minutes. The oxidation reduction potential (ORP) followed, although not so quickly, until it reached a low level. The dissolved oxygen and ORP remained at low levels for several hours and then returned to their previous values.

Odors were measured only by the human nose, but were not noticed at the lagoon except when the ORP reached —100 mv. or lower (using a hydrogen electrode). At this ORP a slight urine odor was noticed. No hydrogen sulfide odor was observed at any time. No odors were present on the grassland being irrigated.

Sludge material from the bottom of the lagoon would often rise to the surface and be dispersed by the action of the aerator. There was not an excess of gas with such material, but rather small gas bubbles amid finely divided black particles. A device for measuring bottom sediment was used but very little was found, only about one-half an inch.

As the lagoon was being loaded with manure, any bubbles present on the surface disappeared and any bubbles generated by the floating aerator travelled only four to five feet. The disappearance of the surface bubbles seemed to follow the reduction in dissolved oxygen.



Volatile solids in the lagoon mixed liquor and cumulative (V.S. added minus V.S. irrigated). (Fig. 26)

By plotting the actual mixed-liquor values of BOD_5 and volatile solids in the lagoon versus the cumulative value of the same parameters, a picture of what took place in the lagoon is obtained in Figures 25 and 26. The cumulative values on the charts are the dosage quantities minus the quantities removed by irrigation. Irrigation removed 11 percent of the BOD and 14 percent of the volatile solids. The remaining differences therefore were attributed to stabilization and decomposition by oxidation. Volatile solids reductions of approximately 50 percent were obtained in the lagoon.

SUMMARY AND CONCLUSIONS

This report emphasizes the aerobic method of storage and treatment of livestock wastes (manure) primarily because of the low level of odors associated with aerobic treatment. An introduction to the theory of aerobic treatment is presented along with several laboratory experiments at the University of Illinois and at Purdue University. These laboratory experiments verified the use of the aerobic method for livestock wastes. From these experiments two methods of aerobic treatment were studied and the results were summarized. These were (A) the in-the-building oxidation ditch and (B) the aerobic lagoon (oxidation pond and aerated lagoon). However, work on some of these methods was simultaneously being conducted at other research stations in the United States and in Europe. Some of this related work is also discussed.

The oxidation ditch has proven itself in the field to be capable not only of eliminating objectionable odors from manure pits, but of reducing the BOD_5 pollutional value of the waste by about 90 percent. In addition, the volatile solids can be reduced about 40 to 50 percent (admittedly, it is difficult to run accurate BOD and solid balances in field installations). With gravity overflow to a lagoon, the system can be operated with very little labor. There will, however, be digested sludge and surplus water to be removed.

Recommendations for designing in-the-building oxidation ditches for livestock are presented. However, since only the recommendations for finishing hogs have been thoroughly tested, the recommendations for other livestock are to be used only as a guide until they have been further tested. Also, the oxygen supply recommendations are based on that required to satisfy the BOD_5 demand. If reduction of odors is the primary objective, less oxygen supply can perhaps be used, but there is insufficient data to make recommendations to meet some desired degree of odor control. Also, severe foaming can result from the use of insufficient oxygen.

Without further treatment, the effluent from an in-the-building livestock oxidation ditch should not be discharged directly into a receiving stream. Oxidation ditch treatment tends to concentrate plant nutrients and mineral salts and therefore the ditch effluent would disrupt the biological balance of a natural body of water. Even though a 90-percent reduction in the oxygen demand of the waste is possible, the ditch effluent will usually have a demand greater than raw domestic sewage. It also has a reddish-brown color (like weak tea) which makes it undesirable to discharge it into a stream. Hauling or irrigating with or without further treatment is a practical alternative to stream discharge. In this way, the moisture, as well as the nutrient value of the treated waste, can be utilized while avoiding the odor problem of spreading raw manure or anaerobic liquid manure.

The in-the-building oxidation ditch with a continuous discharge is recommended for operator convenience. In this method the manure pit beneath slotted floors is divided into a continuous channel (or channels) for circulating the waste with an aeration rotor (or rotors). This prevents rotor freezing problems and keeps the range of liquid temperature variation to a minimum. Also, the continuous discharge method uses a constant liquid depth and a constant rotor immersion depth (within small variations for minimum power usage). Having the mixed liquor overflow into an aerobic lagoon is also convenient for the operator. The lagoon can have a fluctuating depth so that surplus water can be removed at a convenient time. The simplest method is by use of irrigating equipment.

The method above is a system having practically no odors from manure pit to field. Of course, there may be some objectionable odors in the live-

stock pens where manure splatters. Proper floor and pen design can help prevent odors in the pens by not allowing manure to accumulate in low spots or beneath pen partitions. Also, proper feeding and ventilation methods can reduce odors in the pen area.

The aerobic method can also be utilized in buildings without in-the-building oxidation ditches if some method of periodically flushing the fresh manure into an aerobic lagoon can be devised. The fresh manure must be flushed often enough to keep odors in the pen area to a tolerable level (probably at least two times per day and more often if possible). The aerated deep lagoon allows much less surface area and better temperature control than the oxidation pond. Irrigating mixed liquor from the aerated lagoon removes both sludge and surplus water.

With the variety of methods mentioned above, some form of aerobic treatment should be possible for any livestock setup. There will, of course, be operating expenses involved, but these methods should be attractive alternatives to intolerable odors.

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